Tennessee Weatherization Field Guide

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Tennessee Weatherization Field Guide

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The *Tennessee Weatherization Field Guide* describes the procedures used to analyze the performance of existing homes. In addition, it outlines procedures for improving the effectiveness of insulation, doors, windows, and air sealing details.

In compiling this publication, the authors have benefited from the experience of many individuals who have reviewed our documents, related their experiences, or published information from which we've gained insight. Though we can't name everyone to whom we're indebted, we acknowledge the specific contributions of the following people: Martha Benewicz, Michael Blasnik, Anthony Cox, Bob Davis, Jim Davis, R.W. Davis, Rob de Kieffer, Rick Karg, Rudy Leatherman, Dave Like, Bruce Manclark, David Miller, Rich Moore, Gary Nelson, Russ Rudy, Russ Shaber, Cal Steiner, Ken Tohinaka, John Tooley, Bill Van Der Meer, and Doug Walter. We take full responsibility, however, for the content and use of this publication.

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Foreword

The *Tennessee Weatherization Field Guide* outlines a set of best practices for weatherization agencies. This guide looks at residential structures through the eyes of the auditor and building performance contractor who's main focus is on energy savings and quality control.

The purpose of this guide is to provide specific guidance on evaluating a home's existing condition of insulation, air sealing, heating, cooling, baseload, and health and safety. This guide incorporates information from standards and specifications published by the Building Performance Institute (BPI) and the Standardized Work Specifications and Core Competencies of the Department of Energy's Weatherization Assistance Program (WAP). This guide is also aligned with the International Residential Code (IRC) 2009 and its sister document, the International Energy Conservation Code 2009 (IECC).

The National Renewable Energy Laboratory (NREL) completed a review of this guide in late 2010 that greatly improved its alignment with DOE and BPI standards along with many helpful technical enhancements.

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CHAPTER 1: ENERGY AUDITS AND CUSTOMER RELATIONS

This chapter outlines the energy auditing process as practiced by non-profit agencies and contractors working in the Department of Energy's (DOE) Weatherization Assistance Program (WAP).

The mission of DOE WAP is **"To reduce energy costs for low-income families, particularly for the elderly, people with disabilities, and children, by improving the energy efficiency of their homes while ensuring their health and safety."**

This chapter also discusses ethics, customer relations, and customer education.

1.1 PURPOSES OF AN ENERGY AUDIT

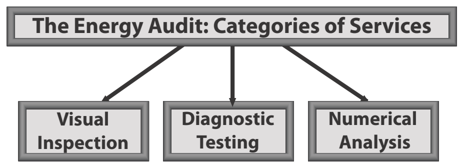
An energy audit is a set of procedures that evaluates a low-income home's existing condition and outlines improvements to the energy efficiency, health, safety, and durability of the home.

An energy audit includes some or all of the following tasks, depending on the level of the audit.

- Inspect the building and its mechanical systems to gather the information necessary for decision-making.
- Evaluate of the current energy consumption along with the existing condition of the building.
- Diagnose areas of energy waste, health and safety, and durability problems related to energy conservation.
- Recommend energy conservation measures (ECMs).
- Project savings expected from ECMs.
- Estimate labor and materials costs for ECMs.
- Diagnose current and potential health and safety problems and how they may be affected by proposed changes.

- Encourage behavioral changes that will reduce energy waste.
- Educate residents about their energy usage and your proposed energy retrofits.
- Provide written documentation of the energy audit and the recommendations offered.

Why We Care about Health, Safety, and Durability



The health and safety of customers must never be compromised by energy auditing or energy conservation measures. Harm caused by our work would hurt both our customers and our profession. Energy conservation work can change the operation of heating and cooling systems, alter the moisture balance within the home, and reduce a home's natural ventilation rate. Energy auditors and contractors must take all possible precautions to avoid harm and instead deliver enhanced safety, indoor air quality, and home durability.

1.2 The Pre-Audit

Visual inspection, diagnostic testing, and numerical analysis are three types of pre-audit procedures we discuss in this section. These procedures should aid you in evaluating all the possible ECMs that are cost-effective according to DOE-approved software: Weatherization Assistant or approved equivalent. *See "SIR Calculations with Weatherization Assistant" on page 22.*

To understand the features of Weatherization Assistant, consult the DOE Weatherization Assistant training web site: www.weatherizationassistanttraining.org.

The pre-audit must also evaluate health and safety concerns, related to the energy conservation measures, and propose solutions as necessary.

1.2.1 Visual Inspection

Visual inspection orients the energy auditor to the physical realities of home and home site. Among the areas of inspection are the following.

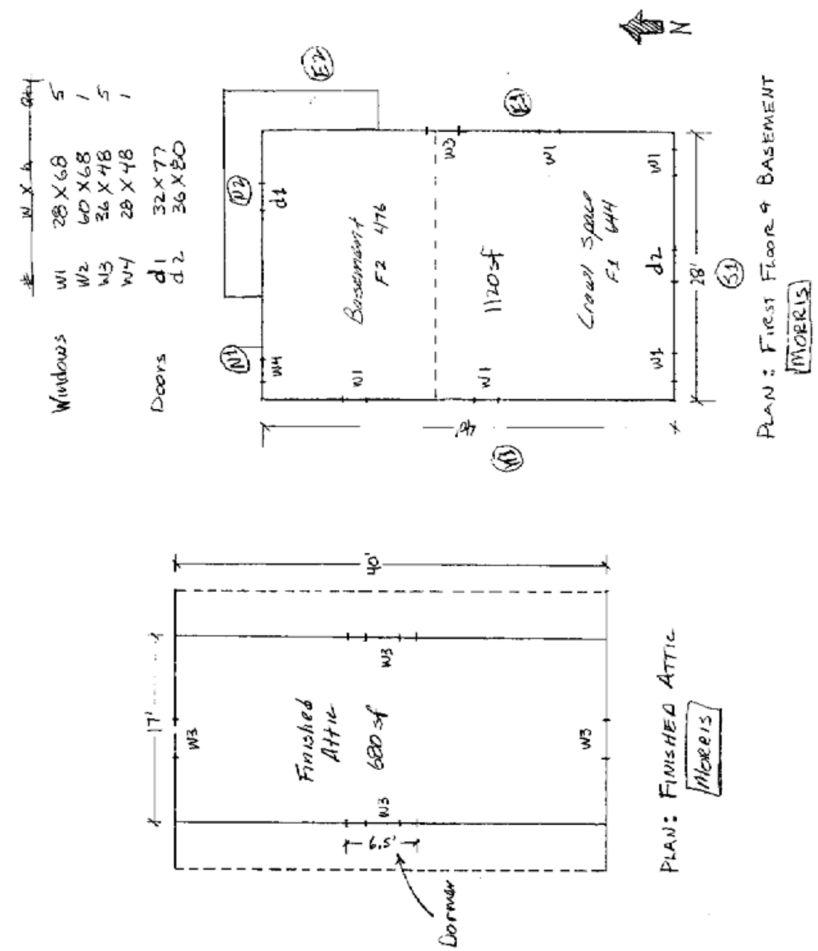
- Building interior and exterior
- Heating and cooling systems
- Baseload energy uses
- Health and safety issues

Inspecting the Building Exterior

The energy auditor should inspect the home from the exterior first, to gain an understanding of the building design, state of maintenance, site issues, floor plan, and main utilities.

- Inspect the characteristics and condition of the foundation, roof, siding, windows, doors, and overhangs.
- Inspect the foundation, and note the amount of exposure.
- Evaluate the site drainage, and look for evidence of moisture accumulation and damage.
- Note any additions to the dwelling.
- View the building through an infrared scanner, if available, to identify thermal flaws.
- Evaluate roof and window shading from trees, awnings, and other buildings.
- Determine which compass orientation each side of the home faces to evaluate the effect of solar heat gain and the opportunity to use solar energy or to block it as appropriate.
- Inspect the chimney(s) and exhaust vents. Note their location and condition.

Visualization: Auditors learn to visualize the home and make simple drawings to aid in communication.

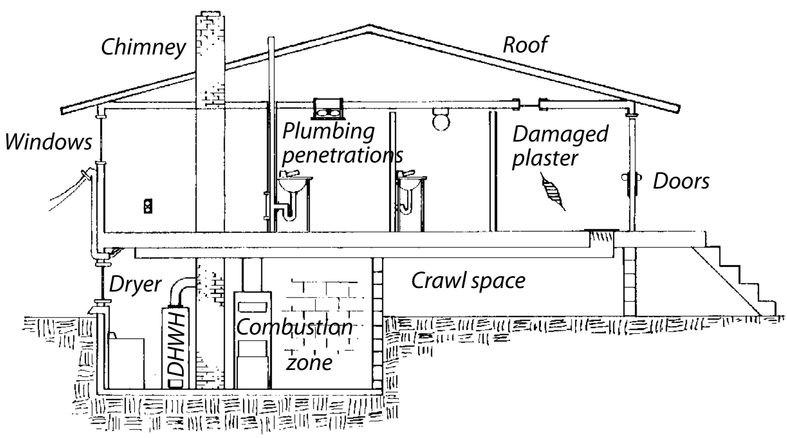


Floor plans: Drawings can help document the home's important characteristics.

Inspecting Dwelling Interior

With the mental map developed from exterior inspection, the interior is then inspected. The following are tasks of an interior home inspection.

- Locate and identify components of the thermal boundary.
- Evaluate the type, thickness, and condition of insulation in the attic, walls, floors, and foundation.
- Look for large air leaks.
- Measure the building's floor space and interior volume.
- Inspect for evidence of moisture problems such as mold, water stains, or musty smells.
- Inspect the wiring in the attic or other areas affected by weatherization measures.
- Identify other health and safety issues.



Interior and exterior inspection: When combined with testing, the inspection of the home's exterior and interior helps the auditor decide on the energy conservation and repair priorities for the home.

Heating System Inspection

Inspect the heating-system to identify problems to be solved during weatherization by a heating technician.

- Look for signs of spillage, backdrafting, and flame rollout.
- Measure the clearance between combustibles and chimneys or vent connectors.
- Compare the size of the venting system with the input rating of the appliances served if you notice spillage or corrosion.
- Inspect all forced-air heat exchangers for deterioration.
- Look for signs of water leaks in water heaters.

Cooling Evaluation

Cooling evaluation includes both the cooling equipment and aspects of the building shell that affect cooling in particular.

- Inspect the roof assembly for shading, insulation, and reflectivity.
- Inspect the attic for adequate insulation level.
- Inspect the windows for shading and solar transmittance.
- Examine room air conditioners and condensing units for dirt and airflow restrictions.
- Inspect central air conditioners for leaks in the condensate tray and drain.
- Inspect the central air conditioner's vapor-line insulation.
- Evaluate the air-conditioning system with professional help as needed.

Baseload Inspection

Baseload energy consumption is comprised of energy uses that remain constant throughout the year, as opposed to seasonal energy consumption such as heating and air conditioning. The water heating system, the refrigerator, lights and the clothes dryer are all important baseload energy consumers and should be evaluated during an energy audit.

- Check for excessive dust on refrigerator's coil.
- Measure refrigerator electricity consumption.
- Refrigerator temperature should be 36–40°F, and freezer temperature should be 0–5°F.
- Inspect the water heater and piping for insulation, leakage and safety problems.
- Water heater temperature should be 120°F.
- Inspect the dryer and dryer vent for lint and debris.
- Inspect lighting and recommend compact-fluorescent replacement bulbs as appropriate.

Health and Safety Inspection

Identify energy-related health and safety deficiencies, which could be caused by or made worse by weatherization activities. Be very careful and courteous about discussing these problems with customers in order not to alarm them needlessly.

- Determine the severity of the deficiencies, and whether there is an immediate threat to the health or safety of household members. **Address emergencies immediately.**
- Check for presence and proper placement of CO detectors and smoke alarms.
- Test for carbon monoxide and depressurization in homes with combustion appliances, tuck under and attached garages, and wood burning stoves.
- Inspect for moisture and other indoor pollution problems.
- Interview the homeowner about the family's health.
- Explain all health and safety problems thoroughly, and answer questions patiently.

1.2.2 Diagnostic Testing

Measurement instruments provide important information about a building's unknowns, such as air leakage and combustion efficiency. The following diagnostic tests are the most common for energy auditing.

Blower door testing: A variety of procedures using a blower door to evaluate the airtightness of a home and parts of its air barrier.

Duct airtightness testing: A variety of tests using a blower door and pressure pan to locate duct leaks.

Note: An advanced duct airtightness test involves pressurizing the ducts with a blower door pressurizing the home which allows for the duct leakage to out side to be determined. While this is a more accurate method to evaluate duct leakage compared to pressure pan testing, it isn't currently the required method in Tennessee. In the event that auditors and contractors have this knowledge and skill-set and are able to conduct such diagnostic tests, they are encouraged to utilize duct pressurization testing.

Combustion safety and efficiency testing: Combustion analyzers sample combustion by-products to evaluate safety and efficiency.

Infrared scanning (Optional): Viewing building components through an infrared scanner, shows differences in the temperature of building components inside building cavities.

Appliance consumption testing: Refrigerators are monitored with logging watt-hour meters to measure electricity consumption.

1.2.3 SIR Calculations with Weatherization Assistant

Energy auditors in Tennessee currently use the DOE-approved software, Weatherization Assistant, to determine which ECMs have the highest Savings-to-Investment Ratio (SIR). In the future however, other State-approved software may be used. The

SIR is the ratio of an ECMs lifetime energy savings to its initial cost.

DOE WAP and the State WAP program require that ECMs have an SIR greater than 1 and that ECMs with higher SIRs be installed before or instead of ECMs with lower SIRs.

Simple measurements and observations are the starting point for computer modeling with Weatherization Assistant and include the following.

- ✓ Measure the home's exterior horizontal dimensions, wall height, floor area, volume, and area of windows and doors.
- ✓ Determine the compass orientation of the home.
- ✓ Calculate electric baseload energy use of the refrigerator.
- ✓ Use The Weatherization Assistant to select energy efficient retrofit measures, generate work orders, and track the weatherization work.

1.3 The Work Scope

The work scope is a list of materials and tasks that are recommended as a result of an energy audit. Use the State-approved software to select the weatherization priorities. Consider the following steps in developing the work scope.

- ✓ Determine which energy conservation activities have an acceptable savings-to-investment ratio (SIR) and belong in the work scope, using approved computer software.
- ✓ Define remedies to health and safety problems.
- ✓ Include sufficient detail to enable contractors to clearly understand the labor and material specifications necessary to complete the job.
- ✓ Inform contractors of any hazards, pending repairs, and important procedures, related to their part of the work scope.

1.4 Post-Audits

Post-audits are required after all work is complete. Post-audits ensure that weatherization services have been provided in a quality manner and that the home is left in a safe condition. The agency must perform a post-audit before counting the home as a completion.

- ✓ Confirm that the specified measures are installed. Inspect the work to ensure that workmanship and materials standards are met.
- ✓ Use an infrared scanner, if available, to inspect insulation and air sealing quality. (optional)
- ✓ Test combustion appliances to confirm that they currently operate in a safe and dependable manner. Perform worst-case draft tests and CO tests.
- ✓ Perform final blower door tests.
- ✓ Make sure that the job site is cleaned up.
- ✓ Specify corrective actions where initial work doesn't meet standards.
- ✓ Review operation of the customer's programmable thermostat, if installed.
- ✓ Review all completed work with the customer.
- ✓ Confirm that the customer is satisfied with the work.

1.4.1 Energy-Auditing Ethics

The auditor's good decisions are an extremely important factor in the success of a weatherization program. Good decisions depend on good ethics.

- ✓ Be competent at the inspection, diagnosis, and software skills necessary for energy auditing.

- ✓ Choose ECMs according to their cost-effectiveness along with DOE and State policy, not personal preference or customer preference.
- ✓ Communicate honestly with customers, coworkers, contractors, and supervisors.
- ✓ Know and understand the requirements of the WAP program, and don't manipulate Weatherization Assistant to achieve a pre-determined outcome.
- ✓ Avoid bias in your influence on the purchasing of materials and the hiring of contractors and installers.
- ✓ Know the limits of your authority, and ask for guidance when you need it.

1.5 Customer Relations

Customer satisfaction depends on the energy auditor's reputation, professional courtesy, and ability to communicate.

Auditors may perform customer-contact duties as required by their employers and the energy programs under which they work.

1.5.1 Communication Best Practices

Making a good first impression is important for customer relations. Friendly, honest, and straightforward communication helps create an atmosphere where problems and solutions can be openly discussed.

Setting priorities for customer communication is important for the efficient use of your time. Auditors must communicate clearly and directly. Limit your communication with the customer to the most important energy, health, safety, and durability issues.

- ✓ Make sure that the customer understands the WAP program and why you are in their home.

- ✓ Listen carefully to your customer's reports, complaints, and ideas about their home's energy efficiency.
- ✓ Discuss health and safety hazards with the customer, including combustion-gas spillage, lead-paint hazard, attached garage issues, and storage of flammable materials.
- ✓ Ask questions to clarify your understanding of your customer's concerns.
- ✓ Agency will make arrangements for additional visits by contractors as necessary.

1.5.2 Customer Interview

The customer interview is an important part of the pre-audit. Even if customers have little understanding of energy and buildings, they can provide useful observations that can save you time and help you choose the right ECMs.

- ✓ Ask the customer about comfort complaints, including zones that are too cold or hot.
- ✓ Ask about family health, especially respiratory problems afflicting one or more family members.
- ✓ Discuss space heaters, fireplaces, attached garages, and other combustion hazards.
- ✓ Discuss drainage issues, wet basements or crawl spaces, leaky plumbing, and mold infestations.
- ✓ Discuss the home's existing condition and how the home will change with proposed retrofits.
- ✓ Identify existing damage to finishes to insure that contractors aren't blamed for existing damage.

1.5.3 Denial of Weatherization Services

When you find major functional problems in a home, sometimes it's necessary to deny the customer weatherization services until those problems are solved. The justification for this denial is the likelihood that installed ECMs would be damaged or rendered ineffective by the home's existing condition. The problems that are cause for denial of services include but are not limited to the following.

- ✓ Major roof leakage
- ✓ Major foundation damage
- ✓ Major mold cultures and other moisture deterioration
- ✓ Major plumbing problems
- ✓ Major electrical problems
- ✓ Major fire hazards

Major behavioral problems may also be a reason to deny services to a customer, including but not limited to the following.

- ✓ Illegal activity on the premises
- ✓ Lack of cooperation by the customer

1.6 CUSTOMER EDUCATION

Customer education is a potent energy conservation measure. A well-designed education program engages customers in household energy management, and assures the success of installed measures.

1.6.1 Reducing Heating Consumption

For many customers, increasing comfort and reducing heating and air conditioning costs are the primary reasons they are interested in a home's performance.

Building Shell

The following are the most important customer-education priorities relating to the building shell.

- ✓ Explain the options for attic, wall, and floor insulation.
- ✓ Explain the options for testing and sealing air leaks in the building shell.
- ✓ Explain how major window upgrades don't fit into the overall home energy package. The installed cost of major window upgrades generally fails to provide an adequate SIR, and so these upgrades aren't recommended by the Weatherization Assistant software.

Forced-Air Systems

The following are the most important customer-related energy measures for forced-air furnaces.

- ✓ Locate the furnace filter and demonstrate how to change or clean it.
- ✓ Show the customer how to open floor registers. Help them remove obstructions like rugs and furniture.
- ✓ Show the customer how to clean supply and return grilles periodically.
- ✓ Explain the process used for testing and sealing air leaks in the duct systems.
- ✓ Show the customer how to use a programmable thermostat if they have one or if one will be installed. Explain that the energy savings are determined by the number of degrees of temperature-setpoint reduction and the amount of time the setpoint is reduced.

1.6.2 Reducing Electric Baseload

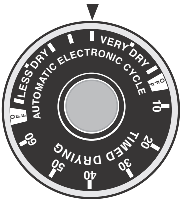
Electric baseload includes the refrigerator, lighting, the clothes dryer and other loads such as computers, TVs, and entertainment equipment. Water heating and baseload ECMs are discussed in *"Baseload Measures" on page 33*.

- Inspect lighting to determine whether incandescent lighting remains in the home. Recommend replacing incandescent lighting with fluorescent or LED lamps.
- Recommend lighting controls for lights that are frequently left on.
- Inspect the clothes dryer and its vent for lint. Advise the client to remove lint from the dryer and vent.
- Recommend reduction of standby power consumption by using switchable plug strips for entertainment centers, computers, and computer peripherals.
- Advise the customer to buy ENERGY STAR appliances or equivalent.

1.6.3 Reducing Hot Water and Laundry Consumption

The auditor should explain or demonstrate the following habits for reducing hot water and laundry energy costs.

- Advise the customer to wash clothes in cold water unless warm or hot water is needed to get dirty clothes clean. Also advise them to wash and dry full loads of clothes.
- Show the customer how to clean the dryer lint filter after each load.
- Show the customer how to use the electronic or moisture-sensing clothes-dryer cycle. Have them note the dial reading that gets clothes acceptably dry and use that setting consistently.



Modern dryer dials: Somewhere in the middle of the electronic or automatic cycle is the most conservative setting.

- Show the customer how to remove lint and outdoor debris from the dryer vent termination.

- If the water heater has been recently replaced, educate the customer how to drain a gallon or two of water and sediment regularly to keep the tank bottom clean.

1.6.4 Reducing Cooling Consumption

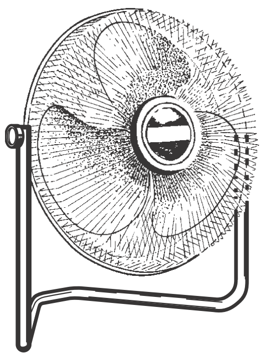
Advise your customers that they can improve their comfort and reduce air conditioning costs by taking these steps.

- Maximize shading and reflectivity of roofs, walls, and windows.
- Use circulating fans to improve comfort in occupied rooms.
- Set the air-conditioner thermostat to 78 degrees or higher.
- Close interior doors to limit the area cooled by room air conditioners.
- Open interior doors and all registers when operating the central air conditioner.
- Clean air-conditioner coils as needed.
- Use a programmable thermostat, or change thermostat settings based on habitual occupancy, such as work and school schedules.
- Avoid using powered attic ventilators because they use a large amount of electricity and tend to increase the home's air leakage.
- Don't operate the air-conditioner blower continuously because blowers use considerable electricity and continuous operation increases both duct leakage and air leakage through the building shell.
- Turn off lights, appliances, and circulating fans when not in use to reduce their heat output and electricity consumption.

Cooling with Ventilation and Fans

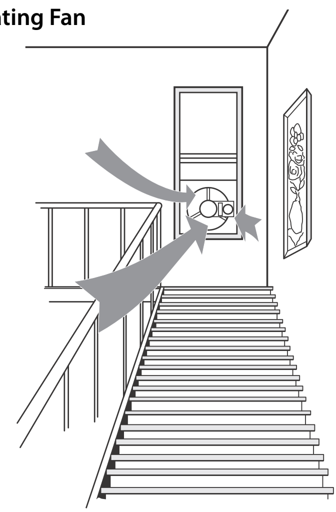
Window fans and whole-house fans are most effective when used at night to remove heat that has collected in the home during the day, except during very humid weather. Set them to exhaust air through a window that is high on the south side of the home, then open a window or door that is low on the north side to admit cool air. Don't use ventilating fans while running an air conditioner. Close windows and draw the drapes or blinds each morning.

Floor fans, table fans, and ceiling fans create a wind-chill effect indoors, which can improve comfort and reduce cooling costs. Since no air is moved out of the home, you can use circulating fans at the same time that an air conditioner is running.



Circulating fan

Ventilating Fan



CHAPTER 2: BASELOAD MEASURES

Baseload energy consumption — water heating, refrigeration, lighting, clothes drying, and plug loads — accounts for a large part of the energy use in most homes. In mild climates, baseload consumption may be larger than heating and cooling combined. Water heating, refrigerators, and lighting are discussed in this chapter.

Table 2-1: Water Heating Consumption According to Family Size

Number of Residents	Annual kWh	Annual Therms	Gallons Per Day
1	2700	180	25
2	3500	230	40
3	4900	320	50
4	5400	350	65
5	6300	410	75
6	7000	750	85

Author's interpretation of data from single-family homes with existing water heaters from Energy Information Administration, Lawrence Berkeley Laboratory, *Home Energy Magazine*, and others.

2.1 WATER-HEATING ENERGY SAVINGS

The most important tasks in evaluating hot water energy savings are determining the water heater's insulation level, measuring the shower's flow rate, and measuring the hot-water's temperature.

2.1.1 Determining the Water Heater's Insulation Level

Common storage water heaters consist of a tank, insulation surrounding the tank, and an outer shell. There is typically either 1 or 2 inches of insulation surrounding the tank. The insulation is either fiberglass or polyisocyanurate.

Follow this procedure to determine the water heater's insulation level.

- ✓ Look for a listing of R-value on a label on the water heater.
- ✓ Find a hole in the outer shell where the flue pipes emerges or where plumbing connects. Look around the hole for either fiberglass or polyisocyanurate insulation.
- ✓ If the hole isn't large enough to see the insulation level on an electric water heater, try removing the access panel for the heating element after disconnecting power from the unit.
- ✓ You may just be able to see the gap between the tank and outer shell. If you can't see this gap, use a ruler or probe to push through the insulation along side of a pipe connecting to the tank until the probe hits the steel tank to deter-

Identifying Tank Insulation

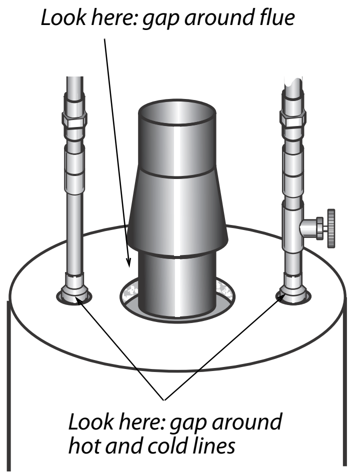


Table 2-2: Insulation R-Values

Insulation/thickness	R
Fiberglass 1 inch	3
Fiberglass 2 inches	6
Isocyanurate 1 inch	6.5
Isocyanurate 2 inches	13
Isocyanurate 3 inches	19.5

mine thickness. Make sure that the probe is against the tank and not against a nut welded to the tank.

✓ If the existing water heater has less than R-10 insulation, specify an R-8 or higher water-heater blanket for the unit. Both fiberglass and "bubble wrap" insulation are acceptable blanket materials.

2.1.2 Water Heater Blankets

Install an insulation blanket on water heaters as recommended by Weatherization Assistant, **unless the manufacturer's label prohibits it**. Follow these guidelines to avoid fire hazards and to simplify future service.

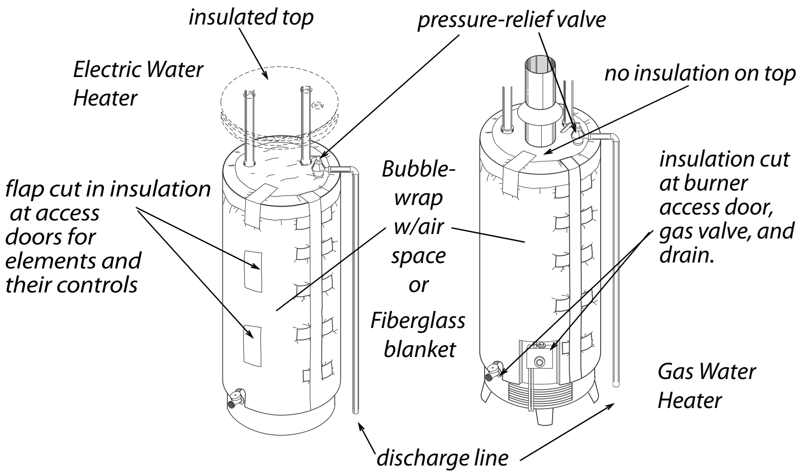
Gas Water Heaters

- Keep insulation at least 2 inches away from the gas valve and the burner access panel. Don't install insulation below the burner access panel.
- Flammable Vapor Ignition Resistant (FVIR) models have combustion intake vents that must be left open. Follow the manufacturer's instructions when installing insulation blankets on FVIR water heaters so to not damage the unit.
- Don't cover the pressure relief valve and discharge line with insulation.
- Don't insulate the tops of gas-fired water heaters to avoid obstructing the draft diverter.

Electric Water Heaters

- Mark the blanket to locate the thermostat and heating element access plates or cut the blanket at these locations. When you cut the blanket, cut the bottom and sides but not the top. This creates a flap that remains closed in-place.
- Don't cover the pressure relief valve and discharge line.

- Cover the top of the water heater with insulation if it doesn't obstruct the pressure relief valve.

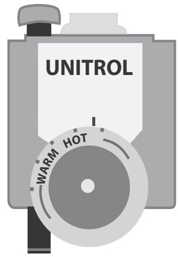


Water heater insulation: Insulation should be installed carefully so it doesn't interfere with the burner, elements, draft diverter, FVIR combustion intake, or pressure relief valve and discharge line. Follow the manufacturer's instructions.

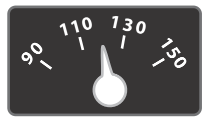
2.1.3 Measuring and Adjusting Hot Water Temperature

- Measure the water heater's water temperature at the nearest faucet to the water heater. Reduce the temperature to 120° F with the customer's permission.
- Use a thermometer to measure the water temperature. Don't rely on the water heater's thermostat reading.
- Set both upper and lower thermostats to the same temperature on electric water heaters. Shut off power to the water heater before opening thermostat access panels.

Setting hot-water temperature: Getting the temperature correct can take a few measurements and re-adjustments.



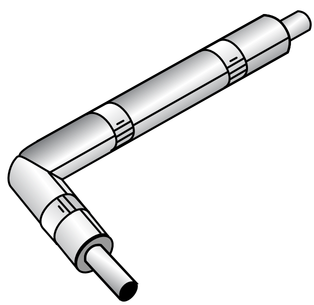
Gas water heater control



Electric water heater control

2.1.4 Water-Heater Pipe Insulation

Install pipe insulation to slow convection of hot water into the water lines near the tank.

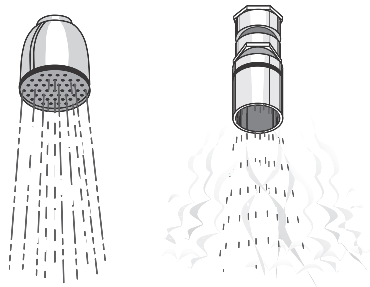


- Insulate the first 6 feet of hot and cold water pipe from the water heater.
- Use pipe wrap with a R-value of at least 2. Cover elbows, unions and other fittings to the same thickness as pipe.
- Keep pipe insulation 6 inches away from single-wall vent pipe and 1 inch away from Type B vent.
- Interior diameter of pipe sleeve must match exterior diameter of pipe
- Fasten with zip ties, tape, or other approved method.

2.1.5 Water-Saving Shower Heads

Most families use more hot water in the shower than for any other use. A low-flow shower head reduces this consumption.

Replace high-flow shower heads with a water-saving shower head rated for a flow of 1.5 to 2.0 gallons per minute. Avoid installing low quality shower heads as they often provide a less satisfying shower and are prone to clogging.



Water-Saving Shower Heads: Two styles of water-saving shower heads give consumers a choice between steamy showers and less steamy ones.

Use caution in removing the existing shower head from old, fragile plumbing systems. To be safe, do not attempt to remove the shower arm that connects the shower head to the fitting inside the wall, but replace just the shower head itself.

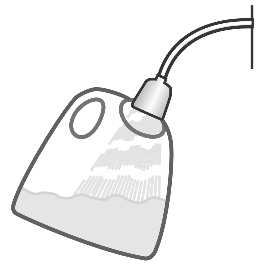
Measuring Shower Flow Rate

You can determine flow rate by measuring the time it takes to fill a one-gallon plastic container. If the one-gallon container fills in less than 20 seconds, your flow rate is more than 3 gallons per minute.

1. Start the shower and set it to the maximum showering rate.
2. Start a stopwatch at the same time you move the container underneath the shower, capturing its entire flow.
3. Note the number of seconds and divide 60 by that number to find gallons per minute.

Measuring shower flow rate: If you divide 60 by the number of seconds needed to fill a gallon container, you will calculate flow in gallons per minute.

$$\frac{1\text{ gal}}{15\text{ sec}} \times \frac{60\text{ sec}}{1\text{ min}} = 4\ \frac{\text{gal}}{\text{min}}$$



2.2 Storage Water Heater Choices

Direct-fired storage water heaters are the most common water heaters found in single-family homes.

Important: All existing and new storage water heaters must have a pressure-and-temperature relief valve and a safety discharge pipe. Install a relief valve and discharge pipe if none exists. The discharge pipe should terminate 6 inches above the floor or outside the dwelling as specified by local codes. The discharge pipe should be made of rigid metal pipe or approved high temperature plastic pipe.

2.2.1 Water-Heater Replacement Decisions

Existing gas water heaters, including propane, typically use 200 to 400 therms per year. New gas water heaters us as little as 175 therms per year, resulting in a savings of around 75 therms per year. Similar savings are possible by replacing electric water heaters. Consider the following recommendations for specifying water heaters.

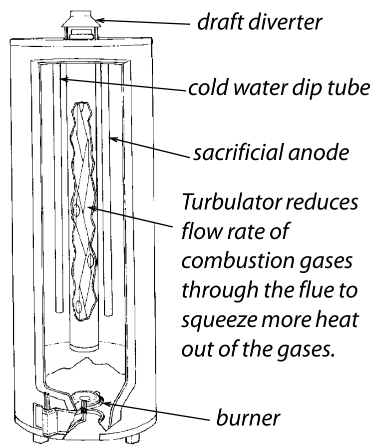
- Any replacement gas or oil storage water heater should have an energy factor of at least 0.67 and be insulated with at least 2 inches of foam insulation.
- Any replacement electric water heater should have an energy factor of at least 0.93 and be insulated with at least 2.5 inches of foam insulation.

2.2.2 Comparing Water Heaters

People often ask whether to install a natural-gas fired, propane-fired, oil-fired, or electric water heater. The choice isn't an easy one and it involves many factors including safety, reliability, efficiency, and installed cost.

Safety Comparison

Conventional direct-fired gas water heaters vent their combustion by-products to a gravity vented chimney. They can spill products of combustion into the living space, especially if the chimney is not tall enough, warm enough, or sized properly. Problems can also be caused by sharing the chimney with another combustion appliance.



Standard gas water heater: These open combustion appliances are often troubled by spillage and backdrafting.

Electric water heaters need no combustion air, which makes them safer for buildings with low natural air leakage, compared to conventional gas storage water heaters.

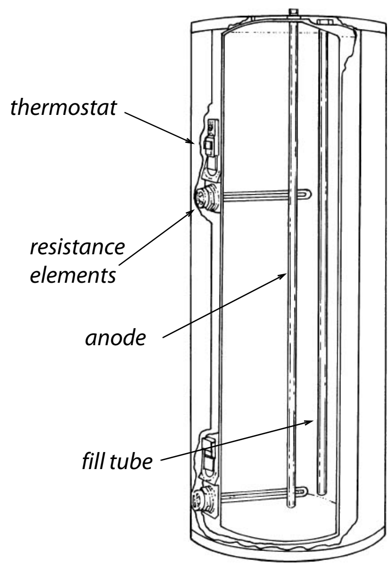
Electric water heaters have no problem with products of combustion. However, because the recovery capacity is generally much less than gas water heaters of the same size, there is a greater chance of someone trying to compensate for a cold shower by turning the electric water heater's control up to an unsafe temperature.

Reliability Comparison

Both gas and electric storage water heaters are simpler and more reliable than any other choice discussed in this chapter. This is why they are so popular. Lifespan depends on local water quality and heater quality. Most heaters have glass-lined steel tanks which are typically warranted for five years. All types of heaters are available with larger or additional sacrificial anodes, which are pieces of metal that corrode before the tank does, thereby extending the tank life and maybe the warranty. Locating a ten-year guarantee heater instead of a five-year guarantee heater, might take a few more phone calls but reduces the future cost of replacement and possible water damage from leaks.

Efficiency Comparison

Conventional gas storage water heaters are rated at about 83% steady-state efficiency. However, whenever a storage water heater isn't firing it is losing heat up the chimney. This happens when cold air flowing through the heater, is warmed by the heater, and escapes up the flue unless the water heater is vented by a power vent. This off-cycle heat loss reduces annual efficiency drastically and may result in the water heater's EF being less than 0.60.



Standard electric storage water heater: Electric water heating is more expensive than gas or oil but safer. Electric water heaters should have at least 2 inches of foam insulation.

The exact energy factor for a particular storage water heater is difficult to estimate because of many factors including: chimney height, diameter, and type; wind near the chimney; availability of air in the home; outdoor temperature; and water heater temperature setpoint. With these variables the actual annual efficiency can vary from 60% down to 40% or possibly even lower for low-use situations.

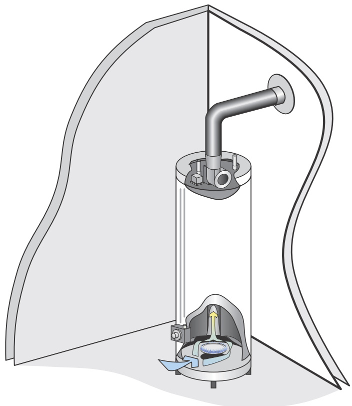
Electric water heaters have no flue and therefore no flue losses. They do lose heat through the insulation jacket, which brings the annual efficiency down to around 90%. Heat-pump water heaters have an efficiency of 200% because they heat water with heat from the surrounding air. But because the electricity production and transmission system in the U.S. is about 31% efficient, the overall energy use and cost for heating water with electricity is usually higher than gas.

Installed Cost Comparison

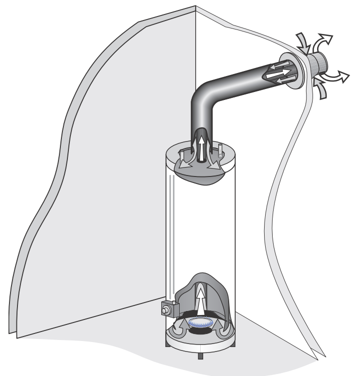
The cost of purchasing a water heater isn't very different between electric and gas conventional models. The installed cost for gas depends more on the availability of a chimney and a gas pipe. Advanced storage water heaters with more than 2 inches of foam insulation are more costly than standard units with one or two inches of foam insulation. Electric storage-water heater installation depends on the availability of a 240-volt electric circuit.

2.3 Water-Heater Replacement

Water heating is one of the greatest energy uses in any home. Unfortunately, standard storage water heaters are an inefficient technology. Tankless heaters offer efficiency benefits, but their initial costs are greater. Solar water heating systems offer a low-emission and sustainable alternative, though their costs are still high. Neither tankless water heaters nor solar water heating systems are currently approved as a ECM in Tennessee.



Fan-assisted water heater: The fan allows horizontal venting.

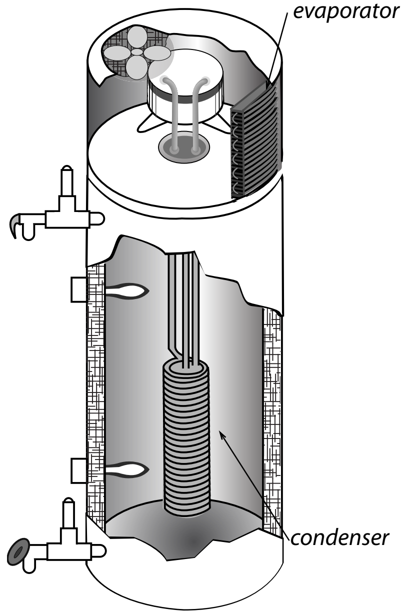


Direct-vent water heater: Moves combustion air and flue gases through a concentric pipe system without a draft fan.

2.3.1 Heat Pump Water Heaters

Heat-pump water heaters heat water with heat they collect from surrounding air and are an excellent choice whenever electricity must be used to heat water. Heat-pump water heaters require installation in locations that remain in the 40°–90°F range year-round and provide at least 1,000 cubic feet of air space around the water heater. Heat-pump water heaters can be an excellent ECM; however heat-pump water heaters are not an approved ECM for Tennessee. The following information is included to for informational purposes.

Heat-pump water heaters cool the spaces they occupy and don't operate efficiently in a location that gets below 45°F. Install heat-pump water heaters in a space with excess heat, such as a boiler room. They provide their best efficiency when both cooling and hot water are needed at the same time.



Heat pump water heater: This heat pump water heaters has the heating coil (condenser) surrounded by the domestic water.

The heating coil or condenser is located inside the tank, wrapped around the tank's exterior, or inside a heat exchanger on top of the tank.

Heat-pump water heaters have energy factors of around 1.8 to 2.3. This means that heat-pump water heaters provide around 2.0 kWh of water heating for each kWh or electricity they consume. Therefore they are approximately twice as efficient as standard electric water heaters.

2.4 Refrigerator Evaluation

The Tennessee WAP requires auditors to meter the refrigerator as the first option. In the event that metering isn't possible, enter the manufacturer and model number in the Weatherization Assistant Program to evaluate the appliance. When you can't read the information plate due to damage, consult a web site for information regarding the unit. When metering isn't possible, place a comment in Weatherization Assistant explaining why the unit wasn't metered.

An alternative option for evaluating refrigerators is to use the resources included in the *Refrigerator Guide* on the WAPTAC web site (www.waptac.org). These resources include a database of refrigerators by model with approximate electricity usage and a refrigerator analysis tool.

Refrigerators built after 1993 use less electricity than refrigerators built before that year and another efficiency increase occurred in 1999. Refrigerators that are replaced should be taken to a facility that is licensed to reclaim their refrigerant and recycle the refrigerator's parts. No refrigerator, taken out of service, should be returned to service by sale, barter, or for free.

The use of multiple refrigerators in homes is common and has a significant effect on electricity usage. Energy auditors should inform customers about the use of more than one refrigerator and suggest consolidating food storage into a large single refrigerator.

2.4.1 Refrigerator Metering Protocol

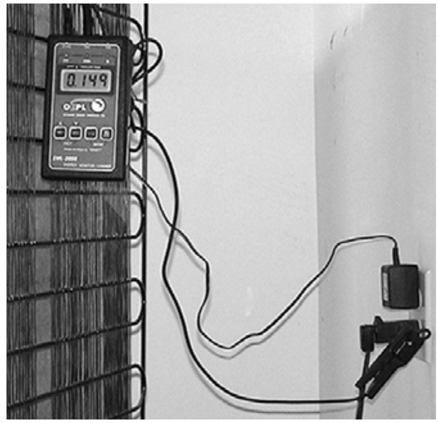
Older refrigerators use from 1000 to 2000 kWh per year. Newer ENERGY STAR (or equivalent) refrigerators use less than 500 kWh per year. This difference presents a good opportunity to significantly reduce electricity consumption.

A minimum of two hours are needed to accurately measure refrigerator energy consumption using a recording watt-hour meter.

A number of unusual circumstances could affect the accuracy of the metering, including the following.

- A quantity of warm food recently placed in the refrigerator.
- Abnormally high or low ambient temperature. For example: refrigerators in garages during the summer or winter or refrigerators in vacant homes where heating or cooling systems aren't operating.

Recording watthour meter: Measures energy consumption over time. The better units can also calculate monthly consumption, or record maximum current draw to help identify the defrost cycle.

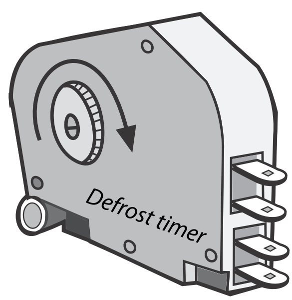


If the refrigerator is an automatic defrost model, an inaccurate reading could result if the unit goes into the electric defrost mode during the test period. This test protocol includes provisions to account for this defrost mode.

1. Determine if the refrigerator is equipped with automatic defrost. This is usually stated on the manufacturer's data plate or on the outside of the unit. If it is *not* so equipped (manual defrost), proceed to step 3.

2. If the unit is equipped with automatic defrost, follow this sub-procedure.

   a. Locate the defrost timer. This small electrical box is usually located behind the front kick-plate, though you may need to move some wires and use a flashlight to see it. It may also be located on the rear of the unit or inside the main compartment behind the lighting panel.



   b. Open the defrost timer and locate the advance pinion. This shaft usually has a screwdriver slot to allow you to manually advance the timer.

   c. Turn the timer clockwise (you can break the timer if you turn counter-clockwise) until you hear a loud click. This turns the defrost heaters on. Turn it 10-20 degrees further until it clicks loudly again, turning the heaters off.

   d. You can now perform your measurement since the timer won't call for defrost heat again for several hours.

3. Connect the refrigerator to a recording watt-hour meter. Run the test for at least two hours. You don't need to stop at exactly two hours, and a longer measurement is O.K. During the test, avoid opening the refrigerator, or do so briefly.

4. At the end of the test, read the kilowatt/hours of consumption measured by the meter. Divide this number by the number of hours in the test. This gives you the number of kilowatts consumed each hour. Multiply this number times the total number of hours in a year (8760 hours per year). The product of this calculation is the annual kilowatt-hours expected to be consumed by the unit.

5. **Plug the refrigerator back into its outlet.**

length of test in hours

number of hours in a year

$$\mathbf{0.32 \div 2 = 0.16 \times 8760 = 1402}$$

kilowatt-hours consumed

hourly consumption in kilowatt-hours

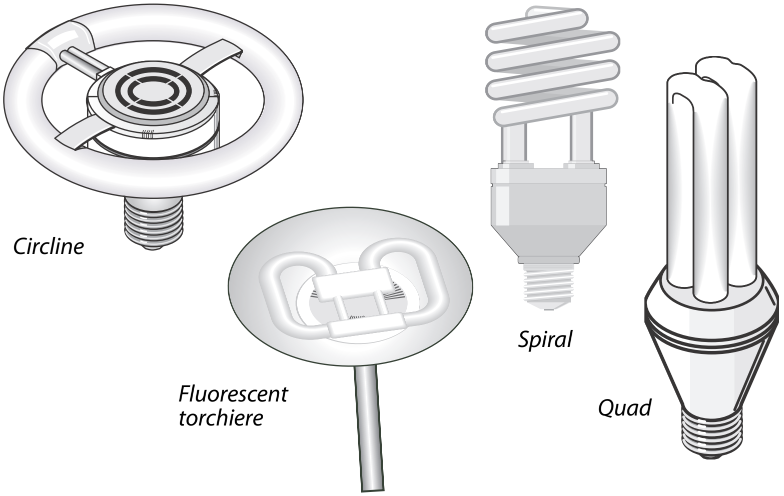
predicted annual consumption in kilowatt-hours

Refrigerator consumption example: In this example, a 2-hour measurement was performed. During this time, the appliance consumed 0.32 kilowatt-hours of electricity, or 0.16 kilowatt-hours for every hour. The annual total of 1402 kilowatt-hours is well beyond the 450 kilowatt-hours per year consumed by today's most efficient refrigerators.

2.5 Lighting Improvements

Most homes have 6 to 12 lamps that burn for more than two hours per day. These should be considered for retrofit by more-efficient compact fluorescent lamps (CFLs). This easy retrofit has as good an economic return as any weatherization measure.

- Ask the customer about their lighting usage, and explain the electrical savings potential for switching to compact fluorescent lamps (CFLs).
- Demonstrate a CFL bulb to the customer if they are unsure about replacing their incandescent light bulbs.
- Select the type of CFL and its wattage, according to its use and the light level to which the customer is accustomed.
- Turn each CFL on after installation to ensure that it operates. Make sure that the customer is satisfied with the lighting level.
- Replace halogen torchieres with fluorescent torchieres.
- Inform customers about proper recycling of fluorescent bulbs by stores, municipal waste departments, or other recycling organizations.



Compact fluorescent lamps: These advanced lamps use about one-third of the electricity of the incandescent lamps they usually replace, and they last about ten times as long.

2.6 Servicing Clothes Dryers

The drying time of a load of laundry is determined by the dryer installation and the amount of lint in the dryer, vent piping, and vent termination. After a few years, lint builds up and slows drying time, increasing energy use and cost. The original installation can also cause excessive drying time when flexible vents are excessively long, kinked, or restricted in some other way.

When insulation is installed in an attic or crawl space, installers may install or repair dryer vent located in those areas as part of the cost of the ECM or as an incidental repair.

Vinyl flexible dryer vent isn't an approved dryer vent material and should be replaced with metal flexible dryer vent if found as part of an ECM or incidental repair.

Observe the following suggestions when servicing clothes dryers to reduce drying time and improve energy efficiency.

- ✓ Unplug the clothes dryer.

- ✓ Remove the vent pipe and vent termination and clean all lint out of them.
- ✓ Clean lint out of the electric heating elements and the air-way around them.
- ✓ Inspect the airway at the dryer's vent connection and clean lint out of it.
- ✓ Dryer vents longer than 3 feet should be piped in 4-inch-diameter rigid aluminum or galvanized pipe.
- ✓ Avoid using screws to join rigid pipe sections because they collect lint. Join and seal the sections with silicone caulking.
- ✓ Use short, stretched pieces of flexible metal dryer vent to connect the dryer to the rigid vent if needed to allow dryer to be moved in and out.
- ✓ If you find flexible dryer vents that are longer than necessary, stretch the flexible pipe and cut it just long enough to allow the dryer to slide in and out of its resting place.

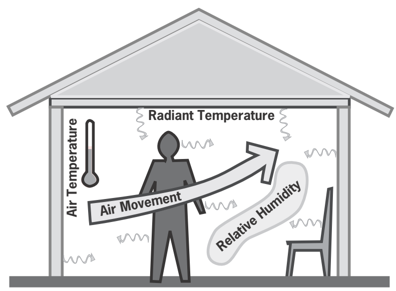
CHAPTER 3: BUILDING SHELL BASICS

The purpose of a building shell is to protect occupants from the excesses of outdoor temperature and moisture. Providing affordable comfort is a goal of modern buildings.

Auditors, installers, contractors should all understand the basics of comfort and the building shell features that provide comfort at an affordable cost. Workers must protect their own health and the safety and the health of their customers. *See "Health and Safety" on page 283.*

3.1 BASICS OF COMFORT

Residents' perception of indoor comfort is primarily based upon four things: the air temperature, air movement, the radiant temperature, and relative humidity. If one of these factors drifts beyond a comfortable range, residents compensate by adjusting the thermostat to a setting that increases energy consumption.

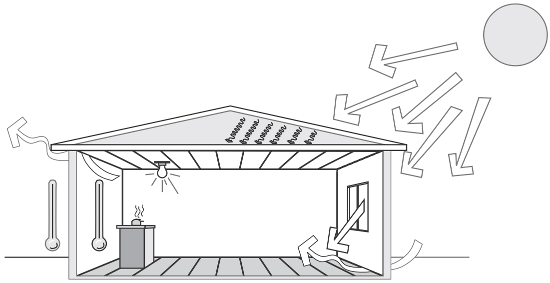


Comfort factors: The perception of comfort is made up of four factors.

3.1.1 Air Temperature

Air temperature, most obvious comfort factor, is the only one that is controlled by your thermostat. In winter, the temperature difference between indoors and outdoors makes heat move across the shell of your home from indoors to outdoors. In summer, the indoor-outdoor difference increases the cost of cooling.

3.1.2 Radiant Temperature



Summer Heat Gains: Solar energy heats homes by shining on roofs, entering through the windows, and heating outdoor air that travels into homes through air leaks. Internal gains, such as appliances and lighting, also release heat into your home.

Your home's radiant temperature is almost as important as its air temperature. Radiant temperature is the temperature of all the objects in the room: the ceilings, floors, and walls and everything else in the rooms. Residents gain or lose heat directly across space to these objects. Cold surfaces hinder comfort in winter and hot surfaces hinder comfort in summer. The radiant temperature of the surfaces determines how much body heat is lost or gained.

R-value is a measure of thermal resistance, which typically varies from 1 to 60. In winter, the indoor-outdoor temperature difference and the R-value combine to determine indoor radiant temperature. Windows have the lowest R-value (1 to 3) and so they have the lowest winter radiant temperatures.

In summer, the sun tends to heat up your attic, often to as high as 150°F. Good shading keeps radiant temperatures low, promoting good comfort and low air conditioning costs. The temperature of the ceiling drywall is directly impacted by shading and the R-value of attic insulation.

3.1.3 Air Movement

In winter you perceive moving air in your home as a cold draft. In drafty homes, residents increase the thermostat setpoint in response. In a drafty home, residents may set the thermostat at 72°F. In a tight home, residents may be just as comfortable at 68°F. Air movement makes a large difference in the heating energy consumption.

In summer, moving air helps comfort. With moving air from fans, residents may be as comfortable at 82°F as they are at 78°F with no moving air. Moving air in from outdoors, with or without fans, can cool a home whenever outdoor temperatures are sufficiently cool and dry, especially at night.

3.1.4 Relative Humidity

Relative humidity is the percentage of water vapor in a particular air mass compared to an air mass at the same temperature that is holding the maximum amount of water vapor possible.

Relative humidity (RH) affects summer comfort because it changes the rate at which moisture evaporates from your skin. Sweat evaporates more quickly in dry weather, and that's why 90°F is a more comfortable temperature in Tucson than it is in New Orleans.

Air conditioning helps control indoor relative humidity during the summer by removing moisture from indoor air. However, air conditioning is an relatively expensive way to control indoor relative humidity. Controlling sources of moisture, such as ground water, plumbing leaks, or plant watering, is important for minimizing air-conditioning energy use.

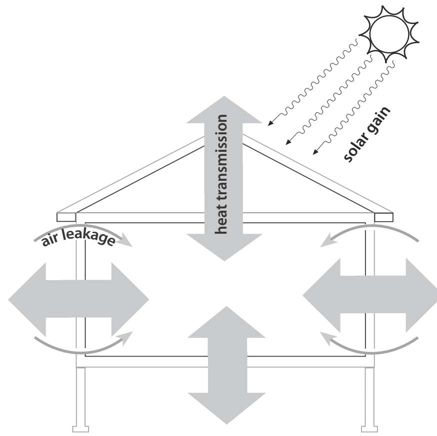
Controlling relative humidity is important to avoid condensation on windows and other cold surfaces during cold weather, but relative humidity isn't a major factor in winter indoor comfort.

Controlling relative humidity is very important for minimizing dust mites and mold, which are major sources of allergy and asthma.

See "Preventing Moisture Problems" on page 294.

3.2 Thermal Flaws in Buildings

Existing buildings have a variety of thermal flaws caused by inadequate design, faulty construction and neglected maintenance. These flaws lead to excessive energy consumption for heating and cooling because they allow excessive heat to travel through the building shell. The thermal weaknesses fall into three (3) broad categories.



Three major factors in providing comfort: The ideal home has optimal thermal resistance, an airtight air barrier, and also an orientation and solar control to use solar heat when needed and stop it when not needed.

- ✓ Inadequate thermal resistance of the building shell.
- ✓ Excessive heat and air leakage through the building shell
- ✓ Lack of shade and inadequate exterior surface reflectance, resulting in excessive summer solar gain through the building shell.

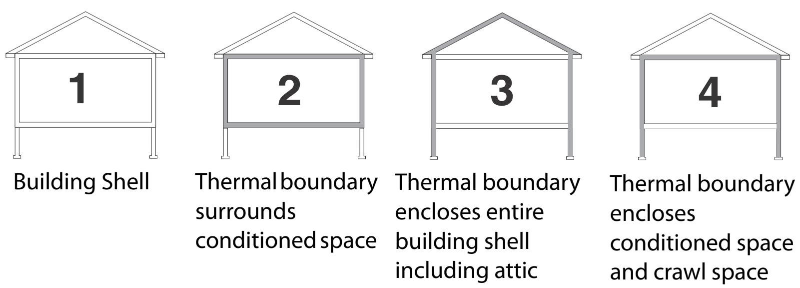
3.3 Shell, Enclosure, and Envelope

Three common terms describe the outermost assemblies of a building. These terms are: shell, enclosure, and envelope. We use shell in this book because it is the simplest and least ambiguous term. Enclosure is also a good term that means the same as shell and is used by many building scientists. Envelope is a common term meaning shell, but envelope is also used to mean a hollow building assembly. These two different meanings for envelope make envelope unsuitable for our purpose of describing the shell of the building.

3.4 Definition: Thermal Boundary

The thermal boundary is a imaginary line, drawn at or inside the building shell, that is useful for discussing heat flow through the building shell. Ideally, an air barrier together with the thermal resistance or insulation is located at the building's thermal boundary. Insulation is responsible for providing adequate thermal resistance between indoors and outdoors. The air barrier is responsible for resisting airflow between indoors and outdoors. *See "Air Barrier Materials" on page 102.*

The thermal boundary's location should be determined by either the building's designer or by an energy specialist who insulates and air seals the building after it is built. Sometimes, no one has thought about the thermal boundary at all in the building and renovation of a home. In this case, you will define the thermal boundary through your energy auditing, insulation, and air-sealing activities.



Typical thermal boundary configurations: The building shell is the outermost building assemblies that enclose the building. The thermal boundary is the line where the insulation and air barrier are installed. Examples 3 & 4 typically have incomplete thermal boundaries because of no insulation or air barrier on the ground underneath the building.

The thermal resistance or insulation and the air barrier work together as a system to limit heat flow across the thermal boundary. The airtightness of the adjacent air barrier has a substantial effect on the building's energy performance. Insulation can retard airflow across the thermal boundary even though insulation's main purpose is to limit heat transmission.

Duct leakage and duct location (either inside the thermal boundary or outside it) are also major energy considerations. If ducts are located outside the thermal boundary, their energy loss is greater than if they are installed inside the thermal boundary.

3.5 Insulation Fundamentals

Insulation provides buildings with better thermal resistance than the structural materials composing the building's structure. Thermal resistance is most commonly measured by the R-value, which is both a material property and a property of multilayer building assemblies.

Insulation materials have R-values that vary from 1.5 to 6.0 per inch of thickness. Non-insulating materials have lesser R-values per inch. R-values of materials in a building assembly are added to arrive at the total R-value of the assembly. *See "R-values for Common Materials" on page 321.*

Insulation resists heat transmission by conduction, convection, and radiation. Insulation minimizes conduction by trapping air with a minimal amount of fibrous material or by trapping either air or a more thermally resistive gas inside foam bubbles. Insulation resists convection and radiation by filling cavities in building assemblies. *See "Installing Insulation" on page 123.*

3.6 Air Leakage and Air Sealing

Traditional buildings typically have a lot of air leaks. Even most modern buildings don't have any building component specifically designed to be an effective air barrier. An air barrier is a building material or assembly that provides adequate resistance to air leakage between conditioned spaces and outdoors.

Controlling shell air leakage is a major factor in a successful energy conservation for buildings. The decisions you make about sealing air leaks affects a building throughout its lifespan.

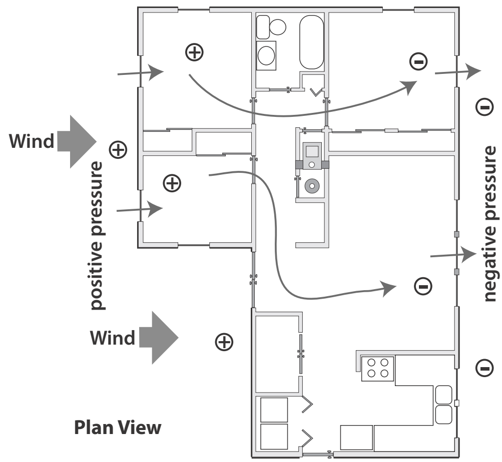
Air leakage creates the following unpredictable effects and problems in buildings.

- Air leakage through insulated assemblies reduces the assemblies' thermal resistance.
- Air leaks create uncomfortable drafts especially in cold weather.
- Air leakage accounts for a significant percentage of a building's heat loss because the incoming air must be heated or cooled much of the year.
- Air leakage moves moisture and pollutants into and out of the house.
- Air leakage causes house pressures that can interfere with the venting of combustion appliances.

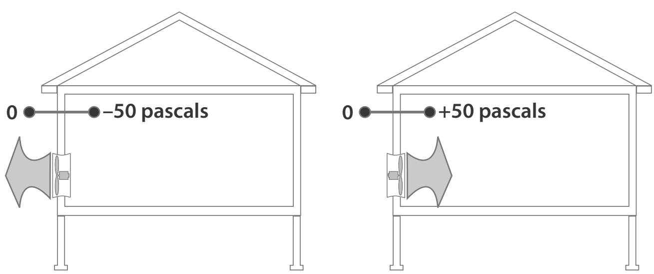
3.6.1 Driving Forces for Air Leakage

For air to flow from one zone to another, there must be a pressure difference between the two zones. A zone, as used in this book, is a region separated from other zones by some kind of air barrier. The greater the pressure difference between zones and the leakier the air barrier between zones, the more the air flows between the zones.

Building height and location, weather, and mechanical equipment all cause pressures that drive air leakage through a building. Strong winds may create a positive pressure on one side of a building, and a negative pressure on the opposite side. A chimney or an exhaust fan creates a negative pressure in the building relative to outdoors. A forced air distribution system depressurizes areas near return ducts and pressurizes areas near supply ducts.



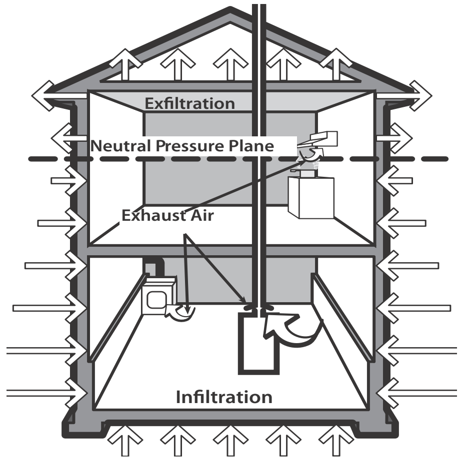
Wind blowing through a home: The wind compresses air on one side (positive pressure) and creates a slight vacuum on the other side of the home.



Blower door pressures: A blower door creates pressure differences that allow air leakage to be measured by instruments.

Pressure is relative. When we depressurize a building during a blower door test, we create an artificial pressure relative to the outdoors. The outdoors is considered to be zero pressure during this test. If the blower door blows air out of the house, the house has a negative pressure relative to outdoors. We also measure pressure between rooms to diagnose air leakage and the driving forces that create air leakage.

Stack Effect and Neutral Pressure Plane



Driving forces for air leakage: Driving sources include stack effect, wind, exhaust fans, and chimneys.

Air moves naturally through a building like gas moving through a chimney. Air tends to enter low in the building (infiltration) and exits at the top of the building (exfiltration) during the heating season. The amount of air entering is equal to the amount of air leaving. This is called the stack effect.

The horizontal plane between the pressurized top and the depressurized bottom of the building is called the neutral pressure plane. Not much air leakage comes in or goes out near the neutral pressure plane. As the building is tightened at the bottom, the neutral pressure plane moves up. As the building is tightened at the top the neutral pressure plane moves down. For the best results, seal air leaks at both the top and bottom of the building. *See "Air Sealing Fundamentals" on page 99.*

Air Sealing and Combustion Safety

Technicians undertake air sealing and duct sealing to save energy by reducing the waste that occurs when air leaks into and out of buildings and/or their ducts. Air sealing and duct sealing may affect combustion appliance venting by making house pressures more negative, thereby reducing the available combustion air supply. After all weatherization is complete, contractors must conduct worst-case spillage testing and re-check the safety of all open-combustion appliances. *See "Carbon Monoxide (CO)" on page 284.*

3.6.2 Air Leakage and Ventilation

We depend on air leakage to provide outdoor air for diluting pollutants and admitting fresh air. However, air leakage is unreliable and often brings pollutants into the home, which is why mechanical ventilation works better than air leakage for providing fresh air.

Air leakage serves as ventilation for removing airborne pollutants in traditional buildings. We have learned that preventing pollutants from becoming airborne, eliminating uncontrolled air leakage, and providing controlled mechanical ventilation are the most efficient ways to provide both good comfort and good indoor air quality.

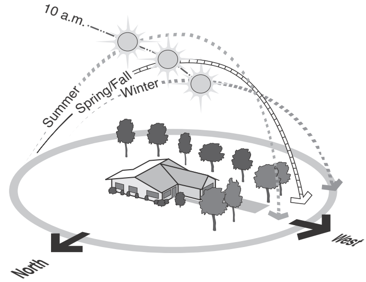
3.6.3 Air Sealing Strategy

The goal of air sealing is to establish a continuous air barrier around all sides of a building. Establishing this effective air barrier in a building requires the following considerations.

- Sealing big leaks first is the most cost-effective air sealing strategy. Sealing big leaks is very cost effective and sealing smaller leaks is less cost effective.
- Installers must plan and install a whole-house mechanical ventilation system for an air-sealed home as part of the weatherization job, unless the home is unusually leaky after air sealing. *See "Evaluating Home Ventilation Levels" on page 74.*

3.7 Shading and Reflectivity Fundamentals

Solar heating through windows, roof and walls is the leading reason buildings use air conditioning to remove accumulated heat. The ideal building has its long axis parallel with an East-West line. This building orientation maximizes solar heat gain in winter and minimizes solar heat gain in summer (in the Northern Hemisphere).



Sun's path relative to home orientation: The ideal home orientation is the long sides of the home facing north and south.

Low-angle sun from the east and west is a heat gain problem for windows facing those directions. A variety of shading options exists to solve these problems starting with special window glass, solar screens, window films, awnings and tree planting. White roofs and walls reflect solar energy and reduce air conditioning energy usage.

Chapter 4: Diagnosing Shell Air Leakage

The testing described here will help you analyze the existing air barriers and decide whether and where air sealing is needed. Ideally an air barrier together with the insulation is located at the building's thermal boundary. The airtightness of the adjacent air barrier has a substantial effect on the insulation's effectiveness. This chapter focuses on pressure-testing homes to determine airtightness and guide air-sealing.

4.1 Shell Air-Leakage Fundamentals

Controlling shell air leakage is a key ingredient to successful weatherization. The decisions you make about sealing air leaks affect a building throughout its lifespan. Air leakage has the following result.

- Air leakage accounts for a significant percentage of a building's heat loss.
- Air leakage through insulated assemblies reduces insulation's R-value.
- Air leakage moves moisture into and out of the house, and so exerts a wetting and/or drying effect.
- Air leakage causes house pressures that can interfere with the venting of combustion appliances.

Air Leakage and Ventilation

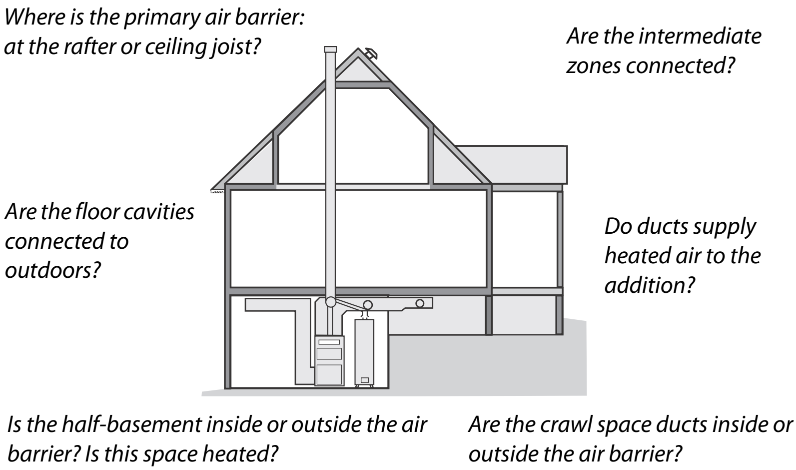
Most homes depend on air leakage to provide outdoor air for diluting pollutants and admitting fresh air. However, air leaks can also bring pollutants into the home. Mechanical ventilation is a more reliable and efficient way to provide fresh air. See *"Evaluating Home Ventilation Levels" on page 74* and *"Whole-House Ventilation Systems" on page 297*.

4.1.1 Goals of Air-Leakage Testing

Air-leakage testing accomplishes a variety of purposes.

- Air-leakage and pressure testing measures the home's air-tightness level.
- Evaluate the home's ventilation requirements.
- Decide how much time and effort is required to achieve cost-effective air-leakage and duct-leakage rates. *See page 235.*
- Compare the air-tightness of the air barriers on either side of an intermediate zone, such as an attic or crawl space. For example, comparing the ceiling with the ventilated roof gives the auditor an idea of how leaky the ceiling is.
- Evaluate the leakiness of individual air barriers like ceilings.
- Decide the best place to establish the air barrier in an area that has no obvious thermal boundary such as an uninsulated crawl space.

The reason for the complexity of air-leakage testing is that there is so much uncertainty about air leakage. Testing is needed because there simply is no accurate prescriptive method for determining the severity and location of leaks, especially in complex homes. Depending on the complexity of a home, you may need to perform varying levels of testing to evaluate shell air leakage.



Questions to ask during an energy audit: Your answers help determine the most efficient and cost-effective location for the air barrier.

Air-Sealing with Air-Leakage Testing

Dedicate most of your effort to seal the large air leaks that pass directly through the thermal boundary first. Chasing small leaks or leaks that connect to the outdoors through interior walls or floors isn't worth as much effort if the budget is limited.

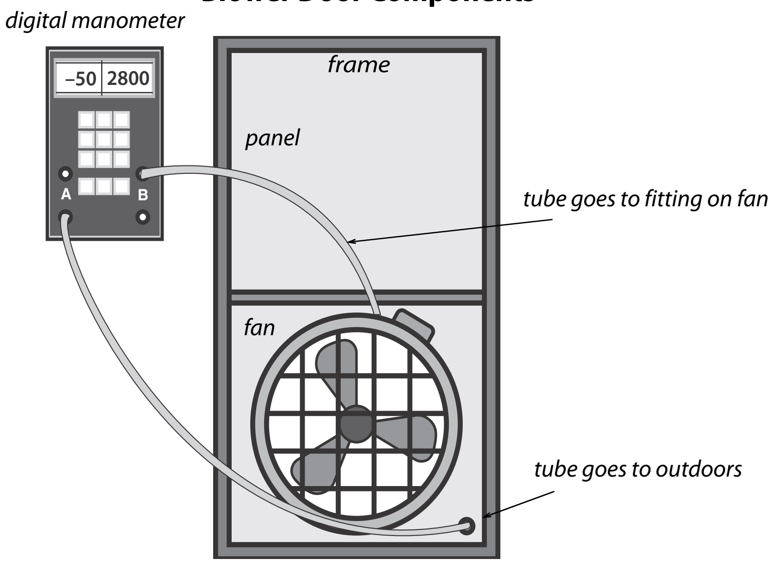
- ✓ Perform pre-audit consisting of blower door testing.
- ✓ Analyze the test results to determine if air sealing is cost-effective using DOE-approved software: Weatherization Assistant.
- ✓ Locate and seal the air leaks.
- ✓ During the post-audit re-test to assess the effectiveness of air sealing efforts.
- ✓ Stop air sealing when air-sealing goals have been achieved or the budget limit has been reached.

4.2 House Airtightness Testing

House airtightness testing was made possible by the development of the blower door. The blower door measures a home's leakage rate at a standard pressure of 50 pascals. This leakage measurement can be used to compare homes with one another and to established air-leakage standards.

The blower door also allows the auditor to test parts of the home's air barrier to locate air leaks. Sometimes air leaks are obvious. More often, the leaks are hidden, and the auditor wants to obtain clues about their location. This section outlines the basics of blower door measurement along with some techniques for gathering clues about the location of air leaks.

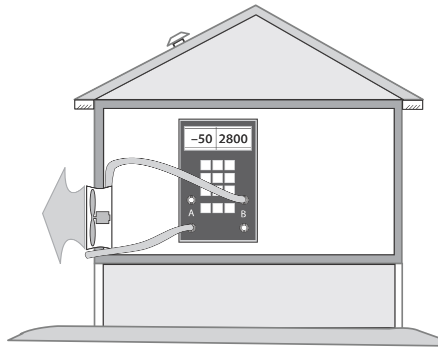
Blower Door Components



4.2.1 Blower-Door Principles

The blower door creates a 50-pascal pressure difference across the building shell and measures airflow in cubic feet per minute at 50 pascals (CFM_{50}), in order to compare the leakiness of homes. The blower door also creates pressure differences between rooms in the house and intermediate zones like attics and crawl spaces. These pressure differences can give clues about the location and combined size of a home's hidden air leaks.

Blower door test: Air barriers are tested during a blower-door test, with the house at a pressure of 50 pascals negative with reference to outdoors. This house has 2800 CFM_{50} of air leakage. Further diagnostic tests can help determine where that leakage is coming from.



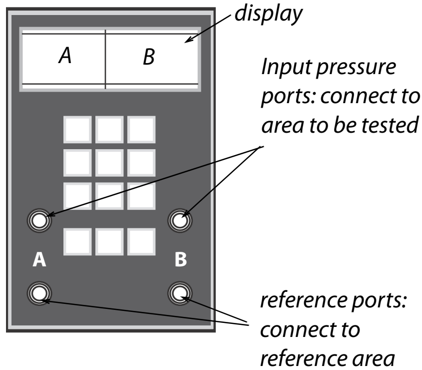
Blower-Door Terminology

Connecting the digital manometer's hoses correctly is essential for accurate testing.

This method uses the phrase *with-reference-to (WRT)*, to distinguish between the input zone and reference zone for a particular measurement. The outdoors is the most commonly used reference zone for blower door testing. The reference zone is considered to be the zero point on the pressure scale.

For example, *house WRT outdoors* = –50 pascals means that the house (input) is 50 pascals negative compared to the outdoors (reference or zero-point). This pressure reading is called the house-to-outdoors pressure difference.

Digital manometers: Used to diagnose house and duct pressures quickly and accurately.



Low-Flow Rings

During the blower door test, the airflow is measured through the fan. This airflow (CFM_{50}) is the primary measurement of a home's airtightness and is directly proportional to the surface area of the home's air leaks. For the blower door to measure airflow accurately, the air must be flowing at an adequate speed. Tighter or smaller buildings don't have enough air leakage to create an adequate airspeed to create the minimum fan pressure. This low-flow condition requires using one of two low-flow rings, commonly provided with the blower door to reduce the fan's opening and increase air speed, fan pressure, and measurement accuracy.

When the air speed is too low, the DG-700 displays "LO" in the Channel B display. After installing one of the low-flow rings, follow the manufacturer's instructions for selecting the proper range or configuration on the digital manometer.

4.2.2 Preparing for a Blower Door Test

Preparing the house for a blower door test involves putting the house in its normal heating-season operation with all conditioned zones open to the blower door. Try to anticipate safety problems that the blower door test could cause, particularly with combustion appliances.

- Identify the location of the thermal boundary and determine which house zones are conditioned.
- Identify large air leaks that could prevent the blower door from achieving adequate pressure, such as a pet-door.
- Put the house into its heating-season operation with windows, doors, and vents closed and air registers open.
- Turn off combustion appliances temporarily.
- Open interior doors so that all indoor areas inside the thermal boundary are connected to the blower door. This could include the basement, conditioned kneewall areas, and closets.

Avoiding Risky Situations

Don't perform a blower door test in risky situations like the following until you remove the risk or perform an acceptable building repair.

- A wood stove is burning.
- Holes in the ceiling may lead to dust pollution during a blower door test.
- Extremely week building components, like a poorly installed suspended ceiling or loose wood wall paneling.
- Occupant has a health condition that may be exacerbated by performing a blower door test.
- Outdoor weather conditions aren't usually a risky situation and should not prevent the completion of a blower door test.

Adjusting for Baseline Pressure

To obtain accurate blower door measurements, you must correct your target house pressure reading on the digital manometer to adjust for wind and stack effect. This adjustment is also referred to as adjusting for the baseline, house with reference to outdoors (*house WRT outdoors*).

Block the blower door's opening to prevent ambient airflow through the fan. Make sure that the house-pressure hose is connected to outdoors and that the fan hose is connected. Measure the baseline house pressure with the blower door off.

Modern digital manometers correct for baseline automatically, when you use the baseline procedure. *See "DG-700 Blower Door Procedures" on page 71.*

4.2.3 Blower-Door Test Procedures

Follow this general procedure when performing a blower-door test.

- ✓ Set up the house for winter conditions with exterior doors, primary windows and storm windows closed. The door to the basement should be either open or closed, according to whether or not the basement is considered to be within the thermal boundary.
- ✓ Install blower door frame, panel, and fan in an exterior doorway with a clear path to outdoors. On windy days, install the blower door on the home's leeward side if possible. Pay attention to the blower door's location and any other conditions that may affect test results.
- ✓ Follow manufacturer's instructions for fan orientation and digital-manometer setup for either pressurization or depressurization. Depressurization is the most common orientation.
- ✓ Connect Channel A of the digital manometer to measure *house WRT outdoors*. Place the outside hose at least 5 feet away from the fan.
- ✓ Connect Channel B to measure *fan WRT zone near fan inlet*. The zone near the fan inlet is indoors for depressurization and outdoors for pressurization. (Hose must run

from the reference port on channel B to outdoors for pressurization.)

- ✓ Adjust for the baseline reading. If the manometer doesn't zero out the baseline automatically, subtract the positive baseline pressure from or add the negative baseline pressure to –50 pascals to manually zero this baseline reading (*house WRT outdoors*). The goal of this adjustment is to apply –50 pascals to the baseline pressure.
- ✓ Ensure that children, pets, and other potential interferences are at a safe distance from the fan.
- ✓ Turn on the fan and increase its speed until you read approximately 50 pascals of pressure difference between indoors and outdoors. Or, use the digital manometer's automatic CFM_{50} speed control.
- ✓ Read the CFM_{50} from channel B of your digital manometer.

DG-700 Blower Door Procedures

Follow these instructions for performing a blower door test, using a DG-700 manometer.

- ✓ Turn on the manometer by pushing the ON/OFF button
- ✓ Push the MODE button twice to set the manometer to read PR/FL@50
- ✓ Push the DEVICE button to select a either a Model 3 or Model 4 blower door.
- ✓ With the fan covered by the no-flow plate, press the BASELINE button to cancel out the background wind and stack pressures.
- ✓ Then push the START button to begin the baseline sampling. Channel B shows the number of seconds. Let the manometer average the baseline pressure for at least 30 seconds.

- ✓ Push the ENTER button to accept the baseline correction. "ADJ Pa" is displayed on Channel A screen and the pressure should be closer to 0 pascals than before you performed the baseline procedure.
- ✓ Remove the no-flow plate from the blower door fan. Complete the next two steps for tighter buildings.

  a. Install the flow ring in the blower door fan which matches the expected flow rate. The fan pressure should be at least 25 Pa.

  b. Push CONFIG button until you match the flow ring (A, B, or C) being used.
- ✓ Turn on the blower door fan slowly with the controller. Increase fan speed until the building depressurization on the Channel A screen is between –45 and –55 pascals. It does not need to be exactly –50 pascals
- ✓ The Channel B screen will display the single-point CFM_{50} air leakage of the building. If this number is fluctuating a lot, push the TIME AVG button to choose 5 or 10 second averaging or long-term averaging.
- ✓ You can also use the cruise-control function to automatically control the fan speed to create and hold –50 pascals of pressure by pressing START and ENTER while in the CFM@50 MODE.

Blower-Door Test Follow-Up

Be sure to return the house to its original condition.

- ✓ Inspect combustion appliance pilot lights to ensure that blower door testing did not extinguish them.
- ✓ Reset thermostats of heaters and water heaters that were turned down for testing.
- ✓ Remove any temporary plugs that were installed to increase house pressure.

- ✓ Document any unusual conditions effecting the blower door test and location where the blower door was installed.

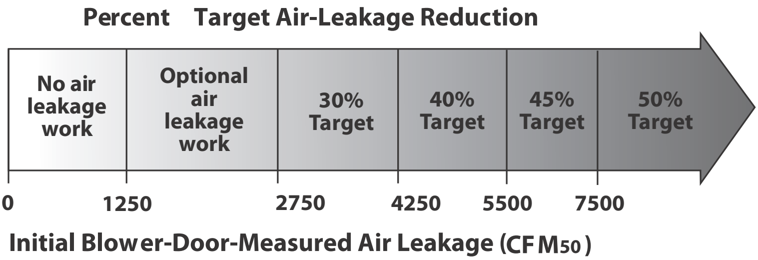
4.2.4 Approximate Leakage Area

There are several ways to convert blower-door CFM_{50} measurements into square inches of total leakage area. A simple and rough way to convert CFM_{50} into an approximate leakage area (ALA) is to divide CFM_{50} by 10. The ALA can help you visualize the size of openings you're looking for in a home or section of a home.

$$\mathbf{ALA = CFM_{50} \div 10}$$

4.2.5 Target Air-Leakage Reductions

Depending on the initial CFM_{50} blower-door test reading, consider the prescribed target air-leakage reduction values specified in the diagram shown next. These percentage reductions aren't national standards but do provide an example of how you might set targets according to an initial blower door reading. This target reduction was designed to work with ASHRAE ventilation standard 62–1989, which is scheduled to phase out in January of 2012. After this date, Tennessee WAP will seek to tighten homes to the minimum economical air-leakage level and install a whole-house ventilation fan as specified by ASHRAE 62.2–2010.



Air-leakage targets: These minimum air-leakage standards are an example of how energy programs have established air-sealing guidelines.

4.3 Evaluating Home Ventilation Levels

Most homes in North America rely on air leakage for ventilation. The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) sets ventilation standards. There are two ASHRAE standards currently being used in North America: ASHRAE 62–1989 and ASHRAE 62.2–2010. Both standards are covered in this section. Consult with your local code jurisdiction to find out which standard is in force locally.

The Tennessee WAP currently uses ASHRAE 62–1989 as the primary ventilation standard. Both ASHRAE 62–1989 and ASHRAE 62.2–2010 are presented to ensure Auditors and Contractors are aware of these ventilation standards. Whole-house ventilation systems are not currently an approved ECM in Tennessee. However, beginning in January of 2012 DOE will be requiring the WAP to apply ASHRAE 62.2–2010 to all homes addressed via the WAP. Mechanical ventilation must be installed if the home's existing air leakage rate is less than the target air leakage rate. This mandate applies under both ASHRAE 62-1989 and ASHRAE 62.2-2010.

The calculated ventilation rates, evaluated under these ASHRAE standards are represented by a number of terms. We prefer and use Minimum Ventilation Guideline (MVG).

The older standard, ASHRAE 62–1989, allows air leakage to serve as ventilation. Air leakage is measured by a blower door in CFM at 50 pascals (CFM_{50}). This standard is associated with the terms: building tightness limit (BTL) and building airflow standard (BAS) but the other terms above may also be used to describe ASHRAE 62–1989.

The newer standard, ASHRAE 62.2–2010, requires fan–powered ventilation in all but very leaky homes and homes in very mild climates. As homes are built with better air-sealing to cope with rising energy costs, they usually require mechanical ventilation systems under ASHRAE 62.2–2010.

The 2009 International Energy Conservation Code (IECC) requires the ASHRAE 62.2–2010 procedure for sizing whole-house ventilation systems and the ASHRAE 62–1989 procedure (0.35 ACH_n) for verifying an adequate natural ventilation rate for homes without whole-house ventilation systems.

4.3.1 ASHRAE 62–1989

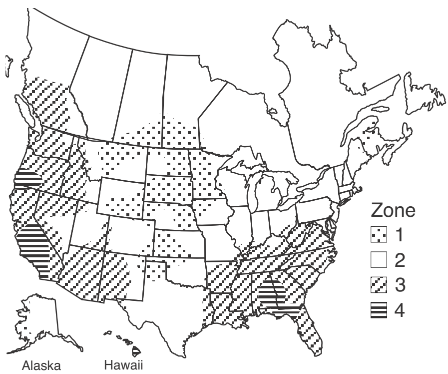
Without fan-powered ventilation, air leaks are the home's only source of fresh air to dilute pollutants. According to standard ASHRAE 62–1989 mechanical ventilation systems must provide fresh outdoor air when the home's air leakage is below the Minimum Ventilation Guideline (MVG) as often estimated using a blower door.

Follow these steps to determine the MVG under 62–1989.

1. Determine the number of occupants by both of the following methods. Choose the larger of the two: a) actual number of occupants, or b) number of bedrooms plus one.
2. Find the home's zone from the map shown on *page 76*.
3. Decide whether the building is well-shielded from wind, "normal", or directly exposed to wind.

4. Find the n-value for the building on the table. This is where the column representing the building's number of stories meets the row representing its location and the shielding. The n-value converts 50-pascal airflow to natural airflow and vice versa.

5. Calculate the MVG using both of the following formulas. Use the larger number of the two: a) 15 CFM per occupant, or b) 0.35 air changes per hour under natural conditions.



Zone	# of stories →	1	1.5	2	3
1	Well-shielded	18.6	16.7	14.9	13.0
	Normal	15.5	14.0	12.4	10.9
	Exposed	14.0	12.6	11.2	9.8
2	Well-shielded	22.2	20.0	17.8	15.5
	Normal	18.5	16.7	14.8	13.0
	Exposed	16.7	15.0	13.3	11.7
3	Well-shielded	25.8	23.2	20.6	18.1
	Normal	21.5	19.4	17.2	15.1
	Exposed	19.4	17.4	15.5	13.5
4	Well-shielded	29.4	26.5	23.5	20.6
	Normal	24.5	22.1	19.6	17.2
	Exposed	22.1	19.8	17.6	15.4

Finding the n-value: Find your zone from the map. Pick the correct column by the number of stories in the building. Then decide how exposed the building is and find the n-value.

$$\text{MVG (CFM}_{50}\text{)} = 15 \text{ cfm} \times \text{\# occupants} \times n$$

$$\text{MVG (CFM}_{50}\text{)} = \frac{0.35 \times \text{volume} \times n}{60}$$

4.3.2 ASHRAE 62.2–2010

To comply with ASHRAE 62.2 – 2010 Ventilation Standard, you can use either the formula or the table shown here to determine the minimum requirement level (MVG) in CFM of fan-powered airflow. ASHRAE 62.2–2010 considers air leakage, as is measured by a blower door in 62–1989, to compute the MVG. Under 62.2–2010, ventilation is provided by a whole-house ventilation fan and also requires a vent fan in all bathrooms and kitchens. The type of fuel used for the cooking appliance does not alter the requirement for a vent fan in the kitchen. A central HVAC system can be used as a supply system by installing a duct to the exterior which provides fresh air. An exhaust system my also be installed to remove indoor air or a combination of both supply and exhaust. The MVG is measured in CFM, and this determines the airflow of the required fans.

Follow these steps to determine the MVG under 62.2 – 2010.

1. Determine the number of occupants by both of the following methods. Choose the larger of the two:

   a. actual number of occupants, or

   b. number of bedrooms plus one.

2. Determine the floor area of the conditioned space of the home in square feet.

3. Insert these numbers in the formula below.

MVG (CFM) = (7.5 cfm x # occupants) + (0.01 x floor area)

You can also calculate the MVG under ASHRAE 62.2–2010 using the table below. *See also "Whole-House Ventilation Systems" on page 297.*

Table 4-1: Fan Sizes for Homes with Average Air Leakage

Floor Area (ft^2)	No. of Bedrooms				
	0–1	2–3	4–5	6–7	>7
< 1500	30	45	60	75	90
1501–3000	45	60	75	90	105
3001–4500	60	75	90	105	120
4501–6000	75	90	105	120	135
6001–7500	90	105	120	135	150
> 7500	105	120	135	150	165

Fan flow in CFM. From ASHRAE Standard 62.2-2010

Local (Spot) Ventilation Requirement

There are two options for complying with the kitchen and bathroom ventilation requirements. Both bathroom and kitchen requirements may be met by dedicated exhaust fans and/or a central ventilation system.

- **Option 1:** Specify that each bathroom receives a minimum of 50 CFM of intermittent exhaust (with appropriate controls), or 20 CFM of continuous exhaust. Also specify that each kitchen receives a minimum of 100 CFM of intermittent exhaust or 5 air changes per hour (ACH) of continuous exhaust based on kitchen volume.
- **Option 2:** If existing ventilation equipment can't be used to fulfill Option 1, and new local-ventilation equipment isn't specified, then airflow from the whole-house ventilation system must be increased to compensate for the insufficiency of local ventilation, according to ASHRAE 62.2–2010.

See also "Fan Specifications" on page 299. See also "Gas Range and Oven Safety" on page 286.

The ASHRAE 62.2–2010 ASHRAE Infiltration Credit

ASHRAE 62.2–2010 allows users to reduce the ventilation-fan airflow by an infiltration credit (I_{cred}) if the actual measured air infiltration (I_{CFM}) is greater than the air infiltration assumed by this ASHRAE standard or I_d. If the I_{CFM} is less than or equal to the assumed air leakage, the home doesn't qualify for the infiltration credit.

Infiltration Credit: $I_{cred} = {}^1/_2 \, (I_{CFM} - I_d)$

Assumed infiltration: I_d **= Floor area X 0.02**

Measured infiltration: $I_{CFM} = CFM_{50} \div N$

Table 4-2: Revised N-Values for 4 Locations in Tennessee

Location	Number of Stories				
	1	1.5	2	2.5	3
Chattanooga	31	27	25	23	22
Knoxville	29	26	24	22	21
Memphis	25	22	21	19	18
Nashville	27	24	22	20	19

Based on w or weather factor from ASHRAE 119 and S-factors based on the number of stories to the power of 0.30

Example: A 3 bedroom 2025 square-foot two-story home in Chattanooga has a measured blower-door air leakage of 2800 CFM_{50}. From the table, the home requires 60 CFM of fan-powered airflow. Does this home get an infiltration credit? How much fan-powered airflow do the air-sealers need to add? Follow the steps below to find the answers.

1. Find I_{CFM}: 2100 CFM_{50} ÷ 25 = 84 CFM

2. FIND I_d: 2025 X 0.02 = 40 CFM

3. Find I_{cred} = $^1/_2$ (84 – 40) = 22 CFM

4. Find adjusted fan CFM: 60 CFM – 22 CFM = 38 CFM

4.3.3 Pollutant Control

Controlling pollutants at the source is a higher priority than ventilation, especially in tighter homes. Mechanical ventilation can help remove and dilute pollutants, but don't rely on ventilation as a sole method of pollutant control. The relative importance of pollution control and whole-house ventilation depend on the following.

- Are sources of moisture like ground water, humidifiers, water leaks, or unvented space heaters causing indoor dampness, high relative humidity, or moisture damage? *See "Moisture Problems" on page 290.*
- Do occupants complain or show symptoms of building-related illnesses? *See also "Health and Safety" on page 283.*
- Are there combustion appliances in the living space? *See also "Essential Combustion Safety Tests" on page 208.*
- Do the occupants smoke?

Pollution-Control Checklist

Contractors should survey the home for pollutants before performing air-sealing, and perform the following pollutant control measures if needed.

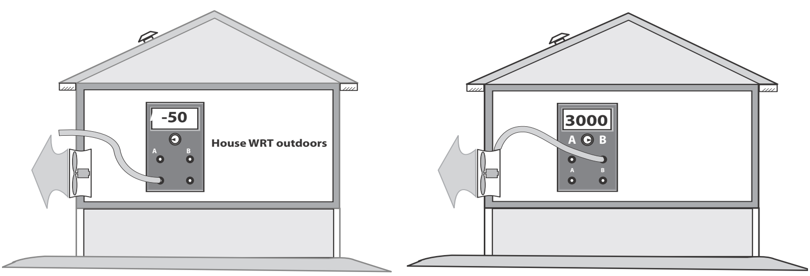
✓ Repair roof and plumbing leaks.

- ✓ Install a ground moisture barrier over any bare soil in crawl spaces or basements.
- ✓ Duct dryers and exhaust fans to the outdoors.
- ✓ Confirm that combustion appliance vent systems operate properly. Don't air seal homes with unvented space heaters.
- ✓ Move paints, cleaning solvents, and other chemicals out of the conditioned space if possible.

The home's occupants have control over the introduction and spread of many home pollutants. Always educate the residents about minimizing pollutants in the home.

4.4 Testing Air Barriers

Leaks in air barriers cause energy and moisture problems in many homes. Air-barrier leak-testing avoids unnecessary visual inspection and air sealing in hard-to-reach areas.



Blower door test: Air barriers are tested during a blower-door test, with the house at a pressure of 50 pascals negative with reference to outdoors. This house has 3000 CFM_{50} of air leakage. Further diagnostic tests can help determine where that leakage is coming from.

Advanced pressure tests measure pressure differences between zones in order to estimate air leakage between zones. Use these tests to make decisions about where to direct your air-sealing efforts.

- Evaluate the airtightness of portions of a building's air barrier, especially floors and ceilings.
- Decide which of two possible air barriers to air seal — for example, the floor versus foundation walls.
- Estimate the air leakage in CFM_{50} through a particular air barrier, for the purpose of estimating the effort and cost necessary to seal the leaks.
- Determine whether building cavities like floor cavities, porch roofs, and overhangs are conduits for air leakage.
- Determine whether building cavities, intermediate zones, and ducts are connected by air leaks.

Air-barrier tests provide a range of information from simple clues about which parts of a building are leakiest, to specific estimates of the airflow and hole size through a particular air barrier.

The table shown next gives the reader examples of how common building materials perform as air barriers. This information is helpful in interpreting blower door tests and selecting air-sealing materials.

Table 4-3: **Building Components and Their Air Permeance**

Good air barriers (<2 CFM_{50} per 100 ft.^{2})	Fair air barriers (2–10 CFM_{50} per 100 ft.^{2})	Poor air barriers (10–1000 CFM_{50} per 100 ft.^{2})
5/8″ oriented strand board	15# perforated felt	5/8″ tongue-and-groove wood sheeting
1/2″ drywall	concrete block	6" fiberglass batt
4-mil house-wrap paper	rubble masonry	1.5" wet-spray cellulose
Asphalt shingles and perforated felt over 1/2″ plywood	7/16″ asphalt-coated fiberboard	wood siding over plank sheathing
1/8″ tempered hardboard	1" expanded polystyrene	wood shingles over plank sheathing
painted uncracked lath and plaster	brick veneer	blown fibrous insulation

Measurements taken at 50 pascals pressure.
Based on information from: "Air Permeance of Building Materials" by Canada Mortgage Housing Corporation, and estimates of comparable assemblies by the authors.

4.4.1 Primary Versus Secondary Air Barriers

The air barrier should be a material that is continuous, sealed at seams, and relatively impermeable to airflow. Where there are two possible air barriers, the most airtight air barrier is the primary air barrier and the least airtight is the secondary air barrier.

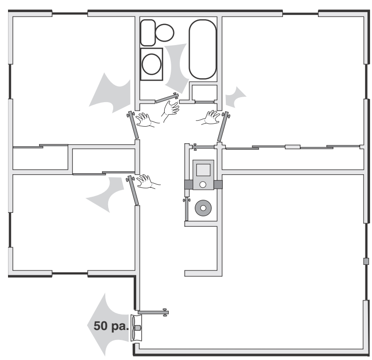
The primary air barrier should be adjacent to the insulation to ensure the insulation's effectiveness. Testing is important to verify that insulation and primary air barrier are together. Sometimes we're surprised during testing to find that our assumed primary air barrier is actually secondary, and the secondary air barrier is actually primary.

Intermediate zones are unconditioned spaces that are sheltered within the exterior shell of the house. Intermediate zones can either be included inside the home's primary air barrier or outside it. Intermediate zones include: unheated basements, crawl spaces, attics, enclosed porches, and attached garages.

Intermediate zones have two potential air barriers: one between the zone and house and one between the zone and outdoors. For example, an attic or roof space has two air barriers: the ceiling and roof. It is useful to know which air barrier is the tightest.

4.4.2 Simple Pressure Tests

You can find valuable information about the relative leakiness of rooms or sections of the home during a blower-door test. Listed below are five simple methods



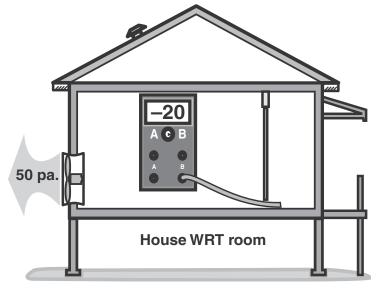
Interior door test: Feeling airflow with your hand at the crack of an interior door gives a rough indication of the air leakage coming from the outdoors through that room.

1. *Feeling zone air leakage:* Close an interior door partially so that there is a one-inch gap between the door and door jamb. Feel the airflow along the length of that crack, and compare that airflow intensity with airflow from other rooms, using this same technique.

2. *Observing the ceiling/attic floor:* Pressurize the home and observe the top-floor ceiling from the attic with a good flashlight. Air leaks will show in movement of loose-fill insulation, blowing dust, moving cobwebs, etc. You can also use a small piece of tissue paper to disclose air movement.

3. *Observing smoke movement:* Pressurize the home and observe the movement of smoke through the house and out of its air leaks.

4. *Room pressure difference:* Check the pressure difference between a closed room or zone and the main body of a home. Larger pressure differences indicate larger potential air leakage within the closed room or else a tight air barrier between the room and main body. A small pressure difference means little leakage to the outdoors through the room or a leaky air barrier between the house and room.



Bedroom test: This bedroom pressure difference may be caused by its leaky exterior walls or tight interior walls, separating it from the main body of the home. This test can determine whether or not a confined combustion zone is connected to other rooms.

5. *Room airflow difference:* Measure the house CFM_{50} with all interior doors open. Close the door to a single room, and note the difference in the CFM_{50} reading. The difference is the approximate leakage through that room's air barrier.

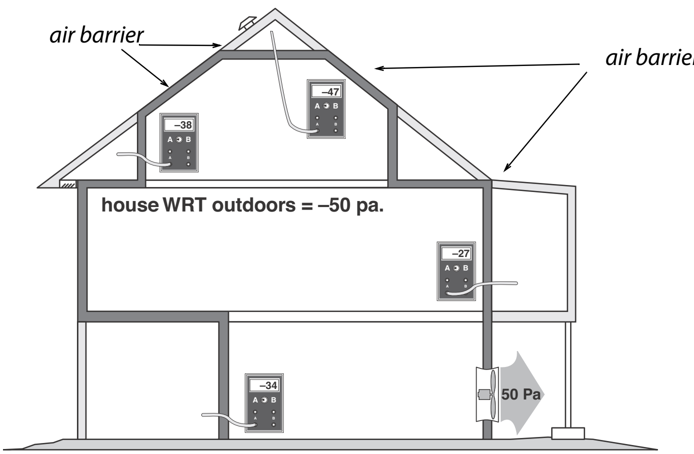
Tests 1, 2, and 3 present good customer education opportunities. Feeling airflow or observing smoke are simple observations, but have helped identify many air leaks that could otherwise have remained hidden.

When airflow within the home is restricted by closing a door, as in tests 4 and 5, it may take alternative indoor paths that render these tests somewhat inaccurate. Only practice and experience can guide your decisions about the applicability and usefulness of these general indicators.

4.4.3 Simple Zone Pressure Testing

A manometer, used for blower-door testing, also can measure pressures between the house and its intermediate zones during blower-door tests.

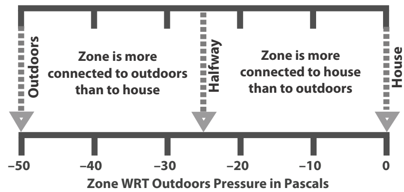
The blower door, when used to create a house-to-outdoors pressure of –50 pascals, also creates house-to-zone pressures of between 0 and –50 pascals in the home's intermediate zones. The amount of depressurization depends on the relative leakiness of the zone's two air barriers.



Pressure-testing building zones: Measuring the pressure difference across the assumed thermal boundary tells you whether the air barrier and insulation are aligned. If the manometer reads close to –50 pascals, the air barrier and insulation are aligned, assuming the tested zones are well-connected to outdoors.

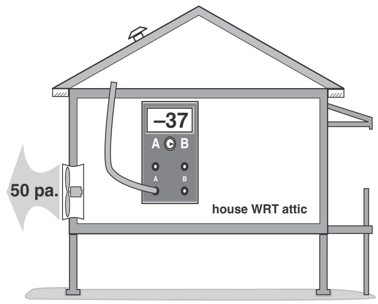
For example, in an attic with a fairly airtight ceiling and a well-ventilated roof, the attic will indicate that it is mostly outdoors by having a house-to-zone pressure of –45 to –50 pascals. The leakier the ceiling and the tighter the roof, the smaller that the negative house-to-zone pressure will be. This holds true for other intermediate zones like crawl spaces, attached garages, and unheated basements.

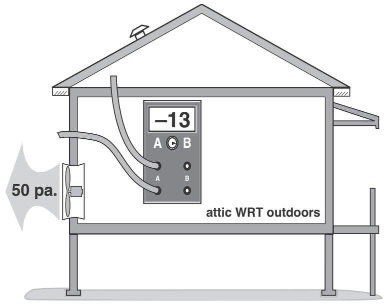
Zone Leak-Testing Methodology



Depressurize house to –50 pascals with a blower door.

1. Find an existing hole, or drill a hole through the floor, wall, or ceiling between the conditioned space and the intermediate zone.
2. Connect the reference port of a digital manometer to a hose connected into the zone.
3. Leave the input port of the digital manometer open to the indoors.
4. Read the negative pressure given by the manometer. This is the house-to-zone pressure, which will be –50 pascals if the air barrier between house and zone is airtight and the zone is open to outdoors.
5. If the reading is significantly less negative than –45 pascals, find the air barrier's largest leaks and seal them.
6. Repeat steps 1 through 5, performing more air-sealing as necessary, until the pressure is as close to –50 pascals as possible.





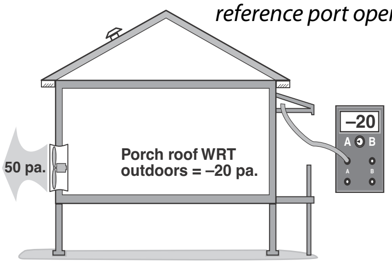
House-to-attic pressure: This commonly used measurement is convenient because it requires only one hose.

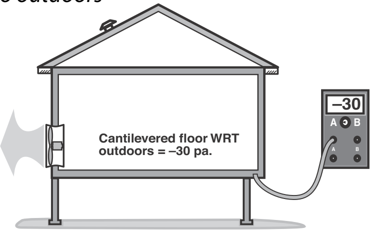
Attic-to-outdoors pressure: This measurement confirms the first because the two add up to –50 pascals.

Leak-Testing Building Cavities

Building cavities such as wall cavities, floor cavities between stories, and dropped soffits in kitchens and bathrooms can also be tested as described above to determine their connection to the outdoors as shown here.

These examples assume that the manometer is outdoors with the reference port open to outdoors



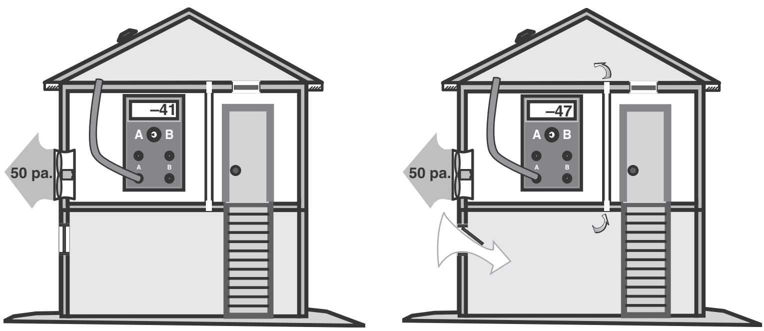


Porch roof test: If the porch roof were outdoors, the manometer would read near 0 pascals. We hope that the porch roof is outdoors because it is outside the insulation. We find, however, that it is partially indoors, indicating that it may harbor significant air leaks through the thermal boundary.

Cantilevered floor test: We hope to find the cantilevered floor to be indoors. A reading of –50 pascals would indicate that it is completely indoors. A reading less negative than –50 pascals is measured here, indicating that the floor cavity is partially connected to outdoors.

Testing Zone Connectedness

Sometimes it is useful to determine whether two zones are connected by an air passage like a large bypass. Measuring the house-to-zone pressure during a blower door test, before and then after opening the other zone to the outdoors, can establish whether the two zones are connected. You can also open an interior door to one of the zones and check for pressure changes in the other.



Zone connectedness: The attic measures closer to outdoors after the basement window is opened, indicating that the attic and basement are connected by a large bypass.

4.4.4 Locating the Thermal Boundary

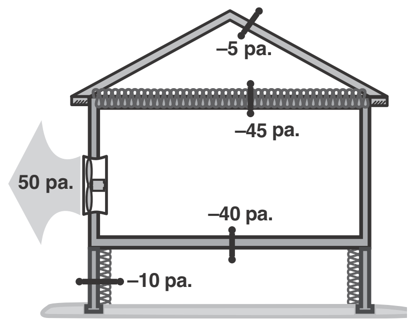
Zone pressures are one of several factors used to determine where the thermal boundary should be. Where to air-seal and where to insulate are necessary retrofit decisions. When there are two choices of where to insulate and air-seal, zone pressures along with other considerations help you decide.

For zone leak-testing, the house-to-zone pressure is often used to determine which of two air barriers is tighter.

- Readings of negative 25-to-50 pascals house-to-attic pressure mean that the ceiling is tighter than the roof. If the roof is quite airtight, achieving a 50-pascal house-to-attic pressure difference may be difficult. However if the roof is well-ventilated, achieving a near-50-pascal difference should be possible.

- Readings of negative 0-to-25 pascals house-to-attic pressure mean that the roof is tighter than the ceiling. If the roof is well-ventilated, the ceiling has even more leak area than the roof's vent area.
- Readings around –25 pascals house-to-attic pressure indicate that the roof and ceiling are equally airtight or leaky.

Pressure readings more negative than –45 pascals indicate that the primary air barrier is adequately airtight. Less negative pressure readings indicate that air leaks should be located and sealed.



Pressure measurements and air-barrier location: The air barrier and insulation are aligned at the ceiling. The crawl-space pressure measurements show that the floor is the air barrier and the insulation is misaligned — installed at the foundation wall. We could decide to close the crawl space vents and air-seal the crawl space. Then the insulation would be aligned with the air barrier.

Floor Versus Crawl Space

The floor shown here is tighter than the crawl-space foundation walls. If the crawl-space foundation walls are insulated, holes and vents in the foundation wall should be sealed until the pressure difference between the crawl space and outside is as negative you can make it — ideally more negative than –45 pascals. A leaky foundation wall renders its insulation nearly worthless.

If the floor above the crawl space were insulated instead of the foundation walls in the above example, the air barrier and the insulation would be aligned.

If a floor is already insulated, it makes sense to establish the air barrier there. If the foundation wall is more airtight than the floor, that would be one reason to insulate the foundation wall.

Attic Boundary

Generally, the thermal boundary (air barrier and insulation) should be between the conditioned space and attic. An exception would be insulating the roof to enclose an attic air handler and its ducts within the thermal boundary.

Garage Boundary

The air barrier should always be between the conditioned space and a tuck-under or attached garage, to separate the living spaces from this unconditioned and often polluted zone.

Duct Location

The location of ducts either within or outside the thermal boundary is an important factor in determining the cost-effectiveness of duct-sealing and insulation. Including the heating ducts within the thermal boundary is preferred because it reduces energy waste from both duct leakage and duct heat transmission.

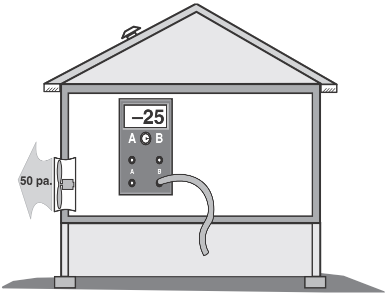
4.4.5 Decisions about Basements and Crawl Spaces

The importance of creating an effective air barrier at the foundation walls or floor depends on how much of the home's air leakage is coming through the foundation or floor.

The energy auditor or contractor may choose either the first floor or the foundation wall as the air barrier. If installing insulation in that building component is also a weatherization priority, the insulation is installed in either the floor or the foundation wall, depending on which was chosen as the air barrier. Most basements and crawl spaces in existing homes are uninsulated.

The results of air-barrier tests are only one deciding factor in selecting the thermal boundary's location. Moisture problems, duct and furnace location, and the necessity of crawl-space venting are other important considerations.

Basement insulation may not be a very practical weatherization option because of moisture concerns, cost, or the need to drywall and tape any newly insulated interior surfaces. Crawl-space insulation poses fewer problems and is often undertaken using foam sheeting, wet-spray cellulose or fiberglass, spray two-part foam, or even foil-faced (FSK) fiberglass.



House-to-crawl-space pressure: Many homes with crawl spaces have an ambiguous thermal boundary at the foundation. Is the air barrier at the floor or foundation wall? Answer: in this case, each forms an equal part of the home's air barrier.

The tables titled: *"Crawl Space: Where Is the Air Barrier?" on page 93* and *"Unoccupied Basement: Where Is the Air Barrier?" on page 94* summarize the decision factors for choosing between the floor and the foundation wall as the air barrier. You may also encounter situations that aren't addressed here.

When a home has a basement and crawl space connected together, both *Table 4-4 on page 93* and *Table 4-5 on page 94* are relevant to the decision-making process of selecting the air barrier and site for insulation, if insulation is cost-effective. A basement may even be divided from its adjoining crawl space to enclose the basement within the air barrier and put the crawl space outside the air barrier.

Table 4-4: Crawl Space: Where Is the Air Barrier?

Factors favoring foundation wall	Factors favoring floor
Ground moisture barrier and good perimeter drainage present or planned	Damp crawl space with no improvement offered by weatherization
Foundation walls test tighter than floor	Floor air-sealing and insulation are reasonable options, considering access and obstacles
Vents can be closed off	Floor tests tighter than foundation walls
Furnace, ducts, and water pipes located in crawl space	No furnace or ducts present
Concrete or concrete block walls are easily insulated	Building code or code official forbids closing vents
Floor air-sealing and insulation would be more difficult than sealing and insulating the foundation	Rubble masonry foundation wall
Foundation wall is insulated	Floor is already insulated

Table 4-5: Unoccupied Basement: Where Is the Air Barrier?

Favors foundation wall	Favors floor
Ground drainage and no existing moisture problems	Damp basement with no solution during weatherization
Interior stairway between house and basement	Floor air-sealing and insulation is a reasonable option, considering access and obstacles
Ducts and furnace in basement	No furnace or ducts present
Foundation walls test tighter than the floor	Floor tests tighter than foundation walls
Basement may be occupied some day	Exterior entrance and stairway only
Laundry in basement	Rubble masonry foundation walls
Floor air-sealing and insulation would be very difficult	Dirt floor or deteriorating concrete floor
Concrete floor	Badly cracked foundation walls

4.5 Controlling House Pressure

House pressures drive air through leaks in the building shell and can cause open-combustion appliances to backdraft. For energy conservation and safety, you should measure house pressures and try to limit them.

The causes of house pressures include the following.

- Duct air leakage
- Unbalanced ducted airflow
- Central ventilation systems
- Exhaust fans in kitchens and bathrooms
- Wind
- Cold weather

4.5.1 Duct-Induced Room Pressures

An improperly balanced air-handling system can reduce comfort, building durability, and indoor air quality. Duct-induced room pressures can increase air leakage through the building shell from 1.5 to 3 times, compared to when the air handler is off.

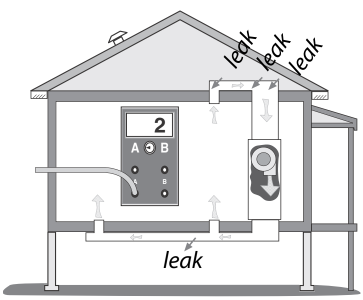
The following test measures pressure differences between the main body of the house and outdoors, between each room and outdoors, and between the combustion zone and outdoors. A pressure difference greater than +4.0 pascals or more negative than –4.0 pascals should be corrected. If the pressure imbalance is the result of occupant behavior such as covering supply or return grilles, discuss these issues with the customer.

Dominant Duct Leakage

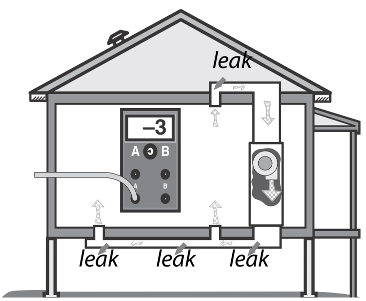
This test helps determine whether duct-sealing efforts should be directed to the supply or return duct system. This test doesn't measure the amount of duct leakage. *See "Evaluating Duct Air Leakage" on page 237.*

1. Set up house for winter conditions. Close all windows and exterior doors. Turn-off all exhaust fans.
2. Open all interior doors, including door to basement.
3. Turn on the air handler.
4. Measure the house-to-outdoors pressure difference.

A positive pressure indicates that the return ducts (which pull air from leaky intermediate zones) are leakier than the supply ducts. A negative pressure indicates that the supply ducts (which push air into intermediate zones through their leaks) are leakier than return ducts. A pressure at or near zero indicates equal supply and return leakage or else little duct leakage.



Dominant return leaks: When return leaks are larger than supply leaks, the house shows a positive pressure with reference to outdoors.



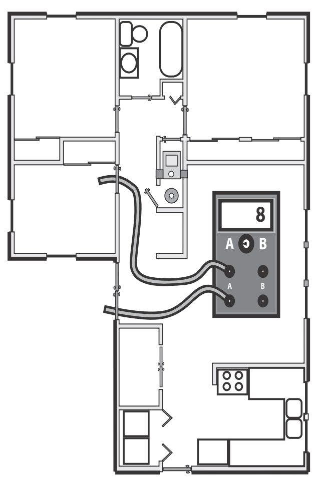
Dominant supply leaks: When supply leaks are larger than return leaks, the house shows a negative pressure with reference to outdoors.

Room Pressure Imbalance

This test identifies room-pressure imbalances caused by closed doors in bedrooms, equipped with supply registers but no return registers.

1. Leave the house in winter conditions, and leave the air handler running.
2. Close interior doors.
3. Place hose from input tap on the manometer under one of the closed interior doors. Connect the reference tap to outdoors with a hose.
4. Read and record this *room-to-outdoors* pressure measurement for each room. This pressure's magnitude indicates the degree to which the air-handler's airflow is unbalanced between supply and return ducts in that room or zone.

If the pressure difference is more than ± 3.0 pascals with the air handler operating, pressure relief is necessary. To estimate the amount of pressure relief, slowly open door until pressure difference drops to between +3.0 pascals and –3.0 pascals. Estimate area of open door. This is the area required to provide the necessary pressure relief. Pressure relief may include undercutting the door or installing transfer grilles.



Blocked return path: With interior doors closed, the large positive pressure in the bedroom is caused by the lack of a air return register in the bedroom. The airflow in this forced-air system is unbalanced, creating this pressure, and forcing room air through the room's air leaks to outdoors.

CHAPTER 5: AIR SEALING HOMES

This chapter discusses the locations of air leaks and the methods and materials used to seal them. Perform air-leakage testing duct-leakage testing before beginning air sealing or duct sealing work. *See "Diagnosing Shell Air Leakage" on page 63.*

5.1 AIR SEALING FUNDAMENTALS

Air leakage in homes accounts for 5% to 40% of annual heating and cooling costs. Air sealing is one of the most important energy-saving retrofits, and often the most difficult.

Air travels into and out of the building by three main pathways.

- Major air leaks, which are significant flaws in the home's air barrier
- Minor air leaks, which are often seams between building materials
- Through the building materials themselves (*See table 4-3 on page 83.*

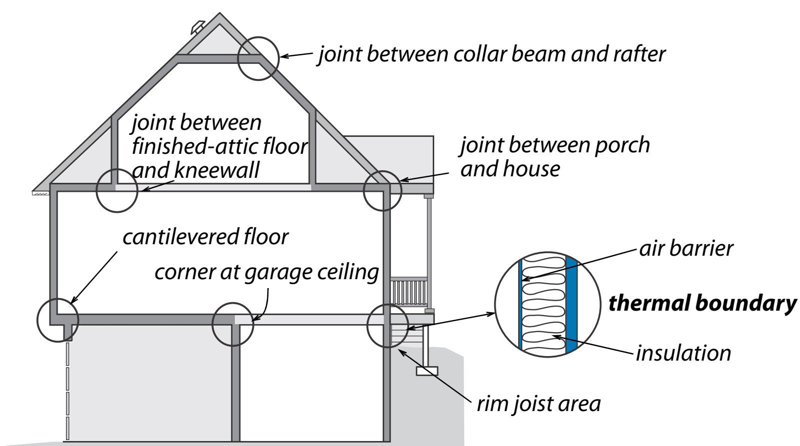
Reducing air leakage accomplishes several goals.

- Saves energy by reducing unintentional air exchange with outdoors
- Saves energy by protecting the thermal resistance of the shell insulation
- Increases comfort by reducing drafts and moderating the radiant temperature of interior surfaces
- Reduces moisture migration into building cavities
- Reduces the pathways by which fire spreads through a building

5.1.1 Air Sealing Strategy

The first step to improving a building's airtightness is to formulate a strategy. Building a strategy starts by asking questions like these.

- What building components already serve as air barriers?
- How do we best seal the border areas between these components?
- Where there is no obvious air barrier, where do we establish one?
- How do we seal various penetrations through the air barrier?
- How does whole-house ventilation relate to shell air leakage? *See "Evaluating Home Ventilation Levels" on page 74.*



Thermal boundary flaws: The thermal boundary contains the air barrier and insulation, which should be adjacent to one other. The insulation and the air barrier are often discontinuous at corners and transitions.

5.2 Air Sealing Safety

Air sealing reduces the exchange of fresh air in the home, and can alter the pressures within the home. Before air sealing, survey the home to identify both air pollutants that may be concentrated by air sealing efforts and open combustion appliances that may be affected by changes in house pressure.

Don't perform air sealing when there are obvious threats to the occupants' health, the installers' health, or the building's durability that are related to air sealing. If any of the following circumstances are present, either postpone air sealing until they're corrected or correct the problems as part of the project's work scope.

- Measured carbon monoxide levels exceed the suggested action level. *See "Carbon Monoxide (CO) Testing" on page 208.*
- Combustion zone depressurization exceeds -4 pascals during a worst-case test. *See "Worst-Case Depressurization, Spillage, and CO" on page 211.*
- Combustion appliance chimneys don't meet minimum standards.
- Unvented space heaters will be used after air sealing work.
- Moisture has caused structural damage or respiratory hazards from rot, mold, or dust mites. *See "Moisture Problems" on page 290.*
- Infestations, vermin, or other sanitary issues are present.

5.3 Air Sealing Materials

Air barriers must be able to resist severe wind pressures. Use strong air barrier materials like plywood, drywall, galvanized steel, or foamboard to seal large air leaks, especially if your region has powerful winds. These strong materials should be attached with mechanical fasteners and construction adhesive.

Caulk should be only be used for sealing small cracks. Use liquid foam for cracks larger than $^1/_4$ inch.

5.3.1 Air Barrier Materials

Air barrier materials should themselves be air barriers. Perforated asphalt felt, concrete block, and earth are among the substantial materials that aren't considered air barriers. The materials discussed below are air barriers. *See also "Building Components and Their Air Permeance" on page 83.*

Plywood, OSB, etc.

Three-eighths-inch plywood and oriented strand board (OSB) are strong enough to resist any windstorm that spares the house. Although combustible and flammable, plywood, OSB, and masonite can be used as ignition barriers and fire stops. Attach these structural sheets with screws or nails and construction adhesive which strengthens the bond and accomplishes air sealing at the joint.

Drywall

Half-inch drywall constitutes a 15 minute thermal barrier, and is also an ignition barrier. When air sealing a fire-rated assembly in a commercial or multi-family building, choose drywall and a fire-rated caulking whenever possible. Fasten drywall with screws and construction adhesive. Don't use drywall where it will get wet or in damp locations.

Galvanized Steel

Being non-combustible, galvanized steel is used to seal around chimneys and other heat producing components. It can be used to build air seals around recessed light fixtures. A round galvanized duct with a galvanized cap makes a good air seal for round recessed light fixtures. To seal around chimneys, cut the galvanized steel accurately so that you can seal the gap with high temperature silicone or stove cement.

Foam Board

One- or two-inch foil-faced polyurethane foam board is easy to cut and fit and is an excellent insulating material. However, foam board is difficult to fasten sufficiently to resist a strong wind event. Plywood, OSB, drywall or other structural materials are far more suitable for sealing large air leaks because of the strong assembly that results by attaching structural air sealing materials to existing structural materials.

Cross-Linked Polyethylene House Wrap

House wrap is vapor permeable, waterproof, and a good air barrier. However it isn't rigid and can be pulled off its fasteners by powerful wind. When used as an air barrier underneath siding, it must be taped at the seams and protected from damage until siding is installed. House wrap is not a very good retrofit air sealing material.

Adhesive Window Flashing

Construction tape and adhesive window flashing can be very effective air sealing materials when used correctly with house wrap or vapor barrier material. Surface preparation is extremely important when using adhesive-backed materials because dust, oil, and moisture can cause the adhesive to fail. The flashing should lay very flat without any tenting in order to allow one-part foam to seal the gap between a new window and the rough opening.

5.3.2 Stuffing Materials

Stuffing materials are used to insulate a cavity, to give the cavity a bottom, or to serve as supporting part of an air seal.

Backer Rod

Backer rod is closed-cell polyethylene foam that creates a bottom barrier in a gap that will be caulked. Backer rod doesn't bond to the caulking, and so prevents three-sided adhesion that could tear the caulking bead apart with the expansion and contraction of temperature extremes.

Fiberglass Batts

Fiberglass batts are far from being an air barrier, even if stuffed tightly. However, they can be used to fill cavities for insulation, convection reduction, and support for two-part foam sprayed over the cavity.

Blown Cellulose

Blown cellulose is considered an air barrier because of its tendency to slow air migration by becoming wedged into gaps and cracks. However it is not much better than fiberglass at stopping air movement. When used to completely fill cavities, it can reduce blower door readings significantly. However, blown cellulose isn't strong enough to resist a windstorm which would blow a hole through the plug of cellulose or simply move it out of the way. Cellulose should never be used in areas where it may get wet.

5.3.3 Caulking and Adhesives

The performance of caulking and adhesives depends on their formulation and on the substrate to which they are applied. Some caulks and adhesives are quite sensitive to dirt and only work well on particular substrates, while others are versatile and dirt-tolerant. Removing debris and cleaning the joint are required for a long lasting seal.

Water Based Caulks

A wide variety of paintable caulks are sold under the description of acrylic latex and vinyl. These are the most commonly used caulks and the easiest to apply and clean up. Siliconized latex caulks are among the most adhesive and durable sealants in this group. Don't apply water based caulks to building exteriors when rain is expected since they are not waterproof until cured, and they stain nearby materials if they are rained upon while curing. Don't apply water based caulks when freezing weather is expected.

Silicone Caulk

Silicone has great flexibility, but its adhesion varies among different substrates. It is very easy to gun even in very cold weather. It's not as easy to clean up as water based caulks, though it's easier than polyurethane or butyl. Silicone is not paintable, so choose an appropriate color. High temperature silicone can tolerate temperatures above 400° F and is used with galvanized steel to air seal around chimneys.

Polyurethane Caulk

Polyurethane has the best adhesion and elasticity of any common caulk. It works very well for cracks between different materials like brick and wood. It resists abrasion and is used to seal critical joints in concrete slabs and walls. It is also good for sealing the fastening fins of windows to walls. It is almost as sticky and adhesive as a construction adhesive. Cleaning it up is difficult so neat workmanship is essential. Polyurethane caulk does not gun easily, and should be room temperature or higher. Polyurethane caulk doesn't hold paint.

Acoustical Sealant

This solvent based or water based adhesive is used to seal laps in polyethylene film and house wrap. Acoustical sealant is very sticky, adheres well to most construction materials, and remains flexible for years after application. Acoustical sealant is used to seal building assembles for sound deadening.

Water Soluble Duct Mastic

Duct mastic is the best material for sealing ducts, including cavities used for return ducts. A messy but highly effective sealant, duct mastic can be applied with a medium thickness brush or rubber glove. Have a bucket of warm water handy to clean your gloved hands and a rag to dry the gloves. Spread the mastic and use fiberglass fabric web tape to reinforce cracks more than $^1/_8$-inch in diameter. Thorough cleaning of dust and loose material isn't necessary. Mastic bonds tenaciously to everything, including skin and clothing.

Stove Cement

Used to seal wood stove chimneys and cement wood stove door gaskets in place. The stove cement should withstand temperatures as high as 2000° F.

Fire-Rated Caulk

Some elastomeric caulks are designed specifically for use in fire-rated assemblies. They can withstand flame and temperatures to 2000° F. Use this type of sealant when sealing air leaks in fire-rated assemblies in multifamily and commercial buildings.

Fire-Rated Mortar

Used in conjunction with foam to seal various sized holes and gaps in commercial buildings with fire-rated building assemblies. This mortar covers the foam to preserve a non-combustible surface.

Construction Adhesives

Construction adhesives are designed primarily to bond materials together. But they also create an air seal if applied continuously around the perimeter of a patch. They are often used with fasteners like screws or nails but can also be used by themselves. Higher quality construction adhesives can be used as contact adhesives to bond lightweight materials. Apply the adhesive to one surface, touch the patch down to spread the glue to both surfaces, then remove the patch to expose the adhesive to air. After a few minutes, put the patch back in place. Make sure you put the patch in the correct location because it will be extremely difficult to remove.

Use specially designed construction adhesives for polystyrene foam insulation because a general purpose adhesives decompose the foam's surface.

5.3.4 Liquid Foam Air Sealant

Liquid closed-cell polyurethane foam is a versatile air sealing material. The low-expansion version of this foam is a DOE approved air sealing material. Closed-cell foam is packaged in a one-part injectable variety and a two-part sprayable variety. It has a very high R-value per inch and is idea for insulating and air sealing small, poorly insulated, and leaky areas in a single application.

One-part foam: A contractor uses an applicator gun to seal spaces between framing members and around windows.

Installation is easy compared to other materials to accomplish the same air sealing tasks. However, cleanup is difficult enough that you probably don't want to clean up multiple times on the same job. Instead identify all the spots needing foam application, make a list, and foam them one after another.

Two-part foam: A contractor air seals and insulates around an attic hatch dam with two-part spray foam.

One-Part Foam

This gap filler has tenacious adhesion. One-part foam is best applied with a foam gun rather than the disposable cans. Cleanup is difficult if you get careless. When squirted skillfully into gaps, this material reduces air leakage, thermal bridging, and air convection through the assemblies to which it is applied. One-part foam isn't effective or easy to apply to gaps over about one inch or to bottomless gaps. This product can leave small air leaks unless applied with skill.

Two-Part Foam

Good for bridging gaps larger than one inch. Two-part foam has become very popular for use with polyurethane foam board to sealing large openings. Cut foam board to close-enough tolerances around obstacles and fill the edges with the two-part foam. Two-part foam should be sprayed to at least an inch of thickness when it serves as an adhesive for foamboard patches over large holes for strength.

Foam Construction Adhesive

Polyurethane foam dispensed from foam guns is an excellent adhesive for joining many kinds of building materials. It works well in joining foam sheets together into thick slabs for access doors through insulated building assemblies.

5.4 Sealing Major Air Leaks and Bypasses

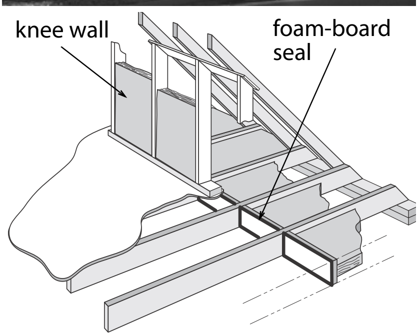
Major air sealing involves finding and sealing large openings that admit outdoor air into the conditioned space. Sealing major air leaks is one of the most cost-effective energy-saving measures.

Major air sealing activities are generally completed prior to insulating where insulation would be an obstacle to air sealing. Effective air sealing results in a significant drop in reduced blower door readings and/or changes in pressure diagnostics readings. *See "House Airtightness Testing" on page 66.*

Bypasses are pathways that allow air to migrate around the insulation. Bypasses are sometimes direct air leaks between indoors and outdoors and sometimes not. In many cases, bypasses merely allow air from indoors or outdoors to circulate around within the building cavities. They can still be a significant energy loss, however, when they are adjacent to interior surfaces of the home where circulating air can convect heat into or out of the home.

Major air leaks are often found between the conditioned space and intermediate zones such as floor cavities, attics, crawl spaces, attached garages, and porch roofs. The time and effort you spend to seal major air leaks should depend on its size.

Major air leaks are not always easily accessible. When they are hard to reach, contractors sometimes blow dense-packed cellulose insulation into surrounding cavities, trusting that the cellulose will resist airflow and plug cracks between building materials.



Sealing under knee walls: Here an undersized piece of foam board is sealed into the joist spaces with one-part foam, forming a strong and airtight seal.

5.4.1 Removing Insulation for Air Sealing

Attics are a particularly critical area for air sealing. The cost of removing insulation from an attic for the purpose of air sealing the attic may be well worth the price. Batts and blankets can be rolled up, moved out of the way, and re-used. Loose fill insulation can be vacuumed with commercial vacuum machines available from the same suppliers that sell insulation-blowing machines. Many insulation companies have these large vacuums already.

5.4.2 Major Air Leak Locations & Treatments

This section provides a list of the most important large air leakage areas commonly found in North American residential buildings. It provides general suggestions for air sealing these areas.

Joist Cavities Under Knee Walls

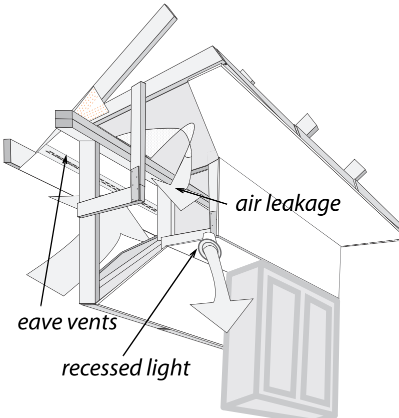
Floor joist cavities beneath knee walls allow air from a ventilated attic space to enter the floor cavity between stories. This is a problem of homes with a finished attic, also known as half-story homes.

Connect the knee wall with the ceiling of the space below by creating a rigid seal under the knee wall. Use a combination of rigid foam with one-part or two-part foam sealing the perimeter. Or, use fiberglass batt or blown cellulose with spray two-part foam as a strong airtight seal covering over the cellulose or fiberglass batt.

Kitchen or Bathroom Interior Soffits

Many modern homes have soffited areas above kitchen cabinets and in bathrooms. Large rectangular passages link the attic with the soffit cavity. At best, the air convects heat into, or out of, the conditioned space. At worst, attic air infiltrates the conditioned space through openings in the soffit or associated framing.

Seal the top of the soffit with foam board, plywood, or drywall fastened and sealed to ceiling joists and soffit framing. Seal the patch's perimeter with two-part foam or caulking.



Kitchen soffits: The ventilated attic is connected to the soffit and the wall cavity through framing flaws. Any hole in the soffit creates a direct connection between the kitchen and attic. The photo shows a soffit sealed from the attic with foam board reinforced with two-part spray foam.

Plumbing Penetrations

Seal gaps with expanding foam or caulk. If the gap is too large, stuff it with fiberglass insulation, and spray foam over the top to seal the surface of the plug.

Seal holes and cracks from underneath with expanding foam. Seal large openings with rigid materials caulked or foamed at edges.

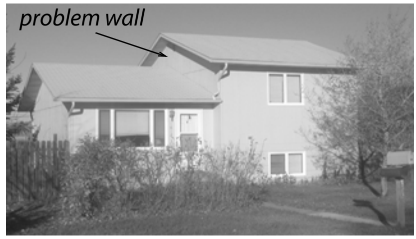
Sealing large plumbing penetrations: Foam board is attached with screws and washers. Gaps around the penetrations are filled with one-part foam to form a complete airtight seal.

Two-Level Attics in Split-Level or Tri-Level Houses

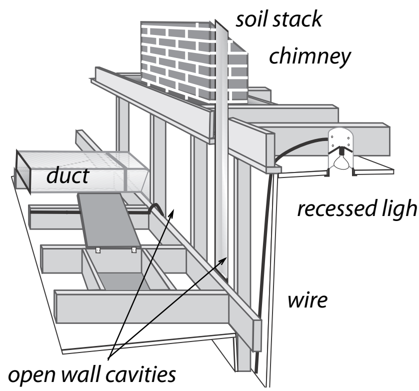
Split-level and tri-level homes have a particular air leakage problem related to the walls and stairways dividing the homes' levels.

Seal wall cavities from the attic with a rigid material fastened to studs and wall material. Or insert folded fiberglass batt and spray with at least one inch of two-part foam to create a rigid air seal. Stapling house wrap to the exposed wall over the insulation retards both air leakage and convection.

Also seal all penetrations between both attics and conditioned areas.



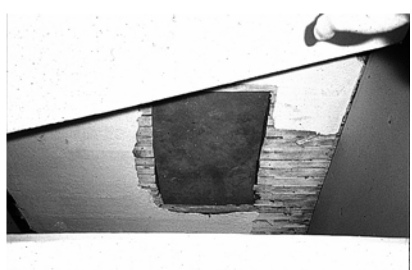
Tri-level home



Two-level attic: Split-level homes create wall cavities connected to the ventilated attic. Other air leaks shown are duct, recessed light, and chimney.

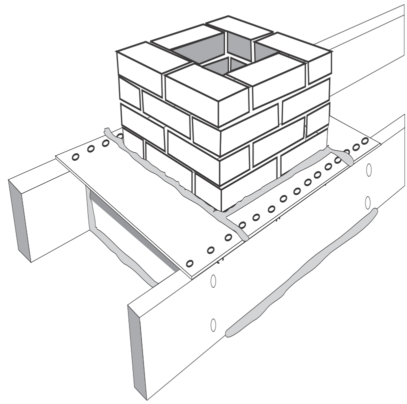
Suspended Ceilings

Suspended ceilings are installed for a variety of reasons, including hiding damage to ceilings and walls. Suspended ceilings are seldom very airtight, especially the T-bar variety. You may have to take down parts of a suspended ceiling to seal the large hidden air leaks in order to get an acceptably tight ceiling.



Fallen plaster: A suspended ceiling hides fallen plaster above.

Fireplace Chimneys



Sealing around chimneys: Chimneys require careful selection of materials for air sealing.

Fireplace chimneys are some of the most dramatic and serious air leaks commonly found in homes. Help the customer decide whether the fireplace will be used in the future or whether it can be taken out of service.

The existing fireplace damper or "airtight" doors seldom provide a good air seal. There are a number of commercial solutions for leaky or non-existent fireplace dampers. They include new tight dampers, tight top sealing dampers, and inflatable pillows. If the fireplace is never used, it can be air sealed from the roof with a watertight, airtight seal and from the living space with foamboard, covered with airtight drywall. If you install a permanent chimney seal such as this, be sure to install a permanent notice in the fireplace.

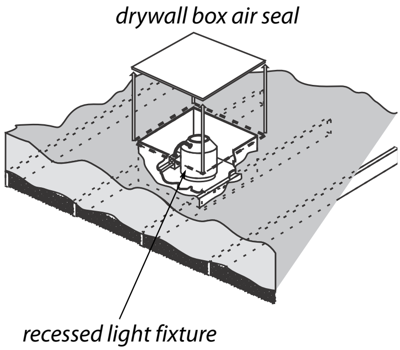
Spaces Around Chimneys

Seal chimney and fireplace bypasses with sheet metal (minimum 26 gauge thickness). Fasten the sheet metal with galvanized nails or screws and construction adhesive. Seal the metal patch to chimney or flue with a high temperature silicone sealant or chimney cement.

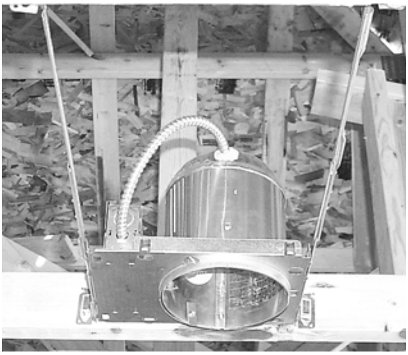
Exhaust Fans and Recessed Lights

Consider the following options for air sealing recessed light and fan fixtures and enhancing the fire safety of the ceiling assembly. Installers may repair bath or kitchen vent pipes as an incidental repair, or as part of ECM costs if those vent pipes are located in attics or crawlspaces that are going to be insulated.

- Caulk joints where housing comes in contact with the ceiling with high temperature silicone sealant to reduce air leakage around the housing.
- Build a metal (26-gauge galvanized steel) or drywall box over the fixture leaving at least 3 inches clearance from insulation on all sides including between the top of the fixture and the lid of the enclosure. Seal the airtight box to surrounding materials with foam to form an airtight assembly.
- Remove the recessed light fixture and patch the opening. Many homes have more light fixtures than necessary.
- Replace the recessed fixture with a surface mount fixture and carefully patch and air seal the hole.
- Replace the recessed fixture with a new one,



Recessed light fixtures: These are major leakage sites, but these fixtures require some air circulation to cool their incandescent bulbs.



Airtight IC recessed light fixtures: Use these fixtures to replace leaky existing fixtures.

designed to be airtight and carefully seal around the airtight fixture.

Recessed light fixtures should contain 60-watt bulbs or less. Compact fluorescent lamps (CFLs) are preferred for recessed light fixtures because CFLs run cooler than incandescent lamps.

Caution: Don't cover IC-rated or airtight IC-rated fixtures with spray foam insulation. The high R-value and continuous contact could overheat the fixture.

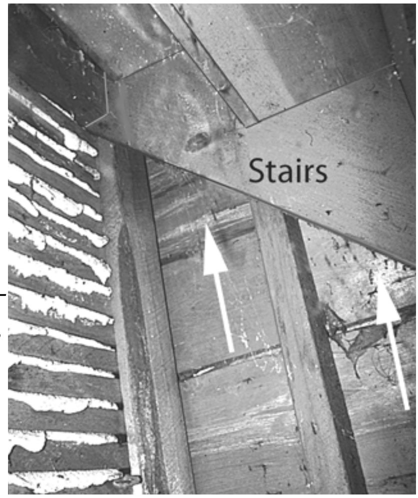
Attic Hatches and Stairways

There are a wide variety of building assemblies for providing access from the building to an insulated attic. These access doors or panels and the framing and sheeting surrounding them often constitute a major air leakage path. Consider the following improvements.

- Weatherstrip around doors and hatches.
- Seal gaps around frame perimeters with one-part foam, two-part foam, or caulking.
- Clear fibrous insulation from around the hatch framing and spray two-part foam around the perimeter to reduce heat loss through the hatch framing.

Incomplete Finished Basements

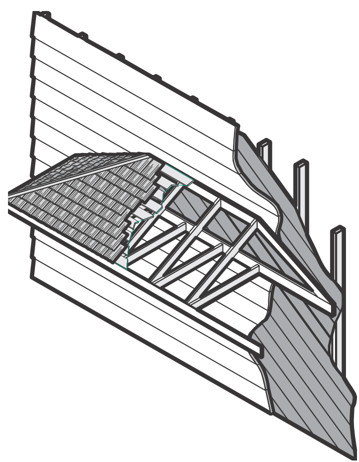
Missing ceilings, wall segments, or rim joist sealing can allow heated basement air to circumvent the finished and insulated wall, carrying heat with it. Complete walls and ceiling or at least install air barriers between finished and unfinished areas. Seal edges of discontinuous walls thoroughly. Seal and insulate untreated rim joists.



Leakage into attic: A closeted space beneath attic stairs provides large air leakage channels into the ventilated attic.

Porch Roof Structures

Porch roofs on older homes were often built at the framing stage or before the water resistive barrier (WRB) and siding were installed. The sheeting around the porch roof sheathing, roofing, and tongue-and-groove ceiling are not air barriers. The plank wall sheathing or unsheathed wall allows air into the wall cavities where it can migrate into the conditioned space or convect heat into or out of the building. This problem requires removing part of the porch ceiling or blowing the entire roof cavity full of cellulose insulation to reduce the airflow through the roof and wall cavities.



Porch air leakage: Porch roof cavities often allow substantial air leakage because of numerous joints, and because there may be no siding or sheathing installed in hidden areas.

Built-In Cabinets/Shelves

Built-in cabinets and shelves are a feature of older homes and present challenges for air sealing. Sealing these areas from inside the cabinet requires care and attention to aesthetics. Use caulking that is compatible with the colors of the surrounding wood. If possible, establish both an air barrier and insulation behind the cabinet, out of sight of the occupants.

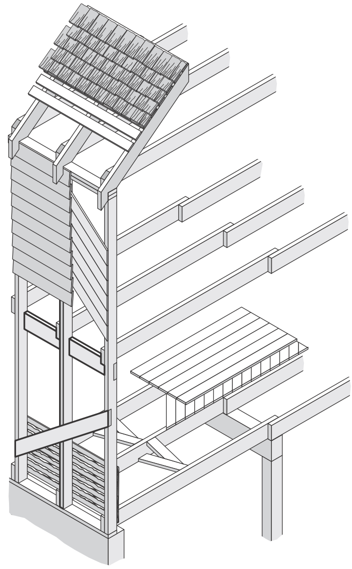
Pocket Door Cavities

When located on the second floor, cap the top of the entire wall cavity in the attic with rigid board, caulked and mechanically fastened.

Cantilevered Floors

Floors that hang over their lower story are called cantilevered floors. The underside of the overhanging floor can leak considerably. If possible, remove a piece of soffit to determine the condition of insulation and air barrier. Use foam board, spray foam, and caulking as necessary to create an air barrier at your chosen thermal boundary. Many balconies have cantilevered floors that leak air into a building's floor cavity.

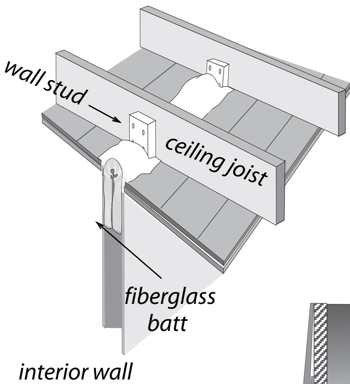
Balloon Framed Walls



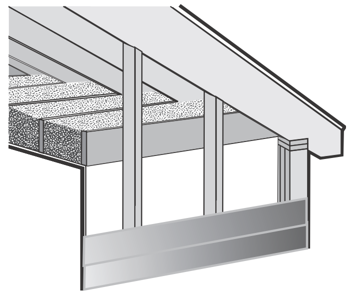
Balloon framed walls: Walls are open to the floor cavity and also to the attic and basement.

Balloon framed two-story walls are common in older homes. Some modern homes have balloon framed gable walls, where the studs rise above the level of the ceiling joists and are cut at an angle to frame the gable. Even when these balloon framed gable walls are full of insulation, air can convect through the insulation. On occasion, windstorms have actually blown the insulation out of the wall cavity into the attic.

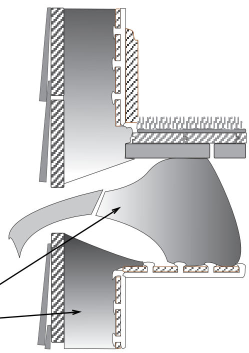
The floor joists are often nailed to long wall studs, creating a continuous cavity through uninsulated wall into the uninsulated floor. Insulate the wall cavities to reduce air leakage and convection. Seal stud cavities from the attic, basement, or crawl space with a fiberglass insulation plug, covered with a 2-part foam air seal. Or seal the cavities with a rigid barrier, such as $^{1}/_{4}$-inch plywood or 1-inch foam board sealed to surrounding materials with caulk or liquid foam.



Balloon framed interior walls: Fiberglass insulation covered by a 1-inch layer of two-part foam seals wall cavities.



Balloon framed gable: Studs extend above the ceiling allowing convection from the attic.



Sealing wall-floor junction: Blown cellulose reduces convection through walls and floors.

5.4.3 Minor Air Sealing

Minor air sealing includes sealing small openings with such materials as caulk, weather stripping, or sash locks. These measures tend to please the home's occupants by reducing perceived drafts, slowing the entry of dirt, or making the interior paint look better. But they rarely result in significant blower door reductions or changes in pressure diagnostic readings.

Silicone bulb weatherstrip: Silicone bulb has its own adhesive or is adhered to surfaces with silicone caulking.

Window and Door Frames

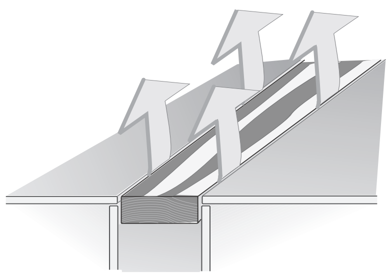
Sealing from the exterior serves to keep bulk water out and protect the building. If the crack is deeper than $^{5}/_{16}$-inch, it should be backed with a material such as backer rod and then sealed with caulk. Any existing loose or brittle material should be removed before the crack is recaulked.

Rim Joist Area

The rim joist area is composed of several joints. They can be sealed from the basement or crawl space with caulk or foam. Remove dust before applying sealant.

Masonry Surfaces

Masonry surfaces are best sealed with a cement-patching compound, mortar mix, or high quality caulking, such as polyurethane. For cement-based patches, consider priming the damaged areas with a concrete adhesive.



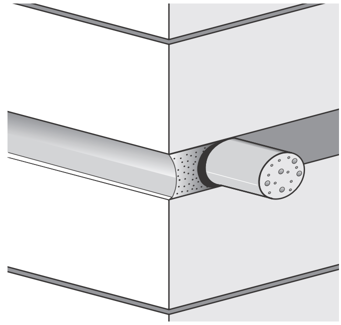
Leaky top plates: The cracks along top plates are from lumber shrinkage. They are small cracks but there are long lengths of them.

Interior Wall Top Plates

Drywall is installed after interior walls are constructed. The top plates of interior walls are open to the attic. Top plate shrinkage opens up cracks that run the entire length of the interior wall. Move insulation and seal the cracks with caulking or two-part foam.

Interior Joints

These can be caulked if blower door testing indicates substantial leakage. These joints include where baseboard, crown molding and/or casing meet the wall, ceiling, and/or floor surfaces. Gaps around surface mounted or recessed light fixtures and ventilation fans can be caulked if needed.



Backer rod: Use it to support caulk when sealing large uniform gaps. Use liquid foam for sealing irregular gaps.

CHAPTER 6: INSTALLING INSULATION

Insulation reduces heat transmission by slowing conduction, convection, and radiation through the building shell. Insulation combined with an air barrier creates the thermal boundary.

Installing insulation is one of the most effective energy saving measures. You can ensure its effectiveness by following these guidelines.

- Protect insulation from air movement with an effective air barrier. Make sure that the air barrier and insulation will be aligned (next to one another) using procedures outlined on *page 64.*
- Protect insulation from moisture by repairing roof and siding leaks, and by controlling vapor sources within the home. *See "Insulation Durability" on page 133.*
- Install insulation in a way that enhances fire safety and doesn't degrade it. *See "Fire Safety" on page 131.*
- Comply with lead-safe practices when disturbing paint in pre-1978 homes. *See "Lead-Safe Procedures" on page 311.*
- Install insulation to meet or exceed the guidelines of the International Energy Conservation Code (IECC) 2009.

Minimum Retrofit Performance Factors for Tennessee

Ceiling R	Wood Wall R	Floor R	Window U	Window SHGC
38	13	19	0.35	0.30

Requirements for Zone 4. From the International Energy Conservation Code and Tennessee Department of Human Services.

While the IECC denotes two zones for Tennessee, Tennessee WAP now uses only Zone 4, which requires more insulation than in previous years.

6.1 Insulation Material Characteristics

The purpose of insulation is to provide thermal resistance, which reduces the rate of heat transmission through building assemblies. Characteristics such as R-value per inch, density, fire safety, and installation effectiveness help contractors choose the right insulation for the job at hand. Insulation may have other useful qualities including vapor permeability or impermeability, and airflow resistance.

The Federal Trade Commission (FTC) Regulation 16 CFR 460.17 requires that installers give their customer a contract or receipt for the insulation installed. This regulation has specific information which must be included in the contract or receipt of the insulation installed. In addition to providing the client with a copy of this contract or receipt, place an additional copy in the client's file.

6.1.1 Fibrous Insulation Materials

Fibrous insulation materials are the most economical source of thermal resistance for buildings. If blown at a high density, fibrous insulations aren't air barriers but may contribute to the airflow resistance of an assembly that functions as an air barrier. The term *mineral wool*, as normally used, describes both fiberglass and *rock wool*. Rock wool is both a generic term and a trade name. We use rock wool in the generic sense as an insulating wool made from rocks or slag.

Cellulose was once made from virgin wood fiber under trade names like Balsam Wool. Now cellulose is manufactured from recycled paper and treated with boric acid or other fire retardants.

Fiberglass Batts and Blankets

Most fiberglass batts are either 14.5 inches wide or 22.5 inches wide to fit 16-inch or 24-inch wood stud or joist spacing. Batt R-values vary from 3.2 per inch to 3.7 per inch depending on density. Fiberglass blankets are available in a variety of thicknesses with vinyl and foil-skrim-kraft facings.

Batts must be installed very carefully to achieve their rated R-value. They insulate best when installed in contact with a good air barrier. Batts are packaged with a number of facings, including foil, kraft and vinyl, but unfaced batts are often the best choice and easiest to install. Although fiberglass is non-combustible, unfaced and faced batts contain flammable binder that holds the batt together. Fiberglass batts have flammable facings.

Fiberglass blankets are used to insulate metal buildings and to insulate crawl spaces from the inside. Although fiberglass doesn't absorb much moisture, the facings on blankets and batts can trap moisture which wets building materials and provides a water source for pests.

Blown Fiberglass

Loose fiberglass is blown in attics from 0.5 to 0.9 pcf and at that density the R-value is around 3.2 per inch. Blown fiberglass is non-combustible as a virgin product, but some blown fiberglass is made from chopped batt waste which contains a a small amount of flammable binder.

Fiberglass manufacturers now provide two blowing products, one for standard densities of up to 1.6 pcf, and another for dense-packing to more than 2 pcf.

In closed cavities, fiberglass is blown from 1.2 to 2.2 pcf, with R-value per inch from 3.6 to 4.2, increasing with higher density. The high density fiberglass is typically reserved for walls where the superior resistance to settling, airflow, and convection has extra value compared to lower density installations.

Blown Cellulose

Loose cellulose is blown in attics from 0.6 to 1.2 pcf and at that density range, the R-value is around 3.7 per inch. Expect around 15% settling within five years after installation.

In wall cavities, cellulose is blown at a higher density of between 3.5 to 4.0 pcf, to prevent settling and to maximize its airflow resistance. At the high density cellulose's R-value per inch is around 3.4. Evaluate the strength of wall cladding before blowing a wall to prevent damage during installation.

Cellulose is also mixed with sprayed water in damp-spray applications in open cavities and adhered to building surfaces. This cellulose material contains a non-corrosive fire retardant to prevent metal corrosion in the building assemblies where it is installed.

Cellulose is the most economical insulation and among the easiest to install. However, cellulose absorbs up to 130% of its own weight in water. Before you know of a moisture problem, the cellulose could be soaked, double its dry weight, and permanently degraded in thermal resistance. Because of its moisture absorption, avoid using cellulose in humid coastal regions or anywhere where it might encounter water or long periods of high relative humidity. Cellulose should not be installed in the following places regardless of climate: crawl spaces, floor cavities above crawl spaces or unconditioned basements, and horizontal or sloped closed roof cavities.

Rock Wool

Rock wool is a type of mineral wool like fiberglass. Rock wool has a small market share in North America. Rock wool batts have similar R-values per inch as fiberglass batts and contain flammable binders. Rock wool itself is non-combustible so blown rock wool will not burn.

6.1.2 Foam Insulation Materials

Foam insulation is commonly sprayed or injected as a liquid or as fastened to building assemblies as foam board.

Caution: Workers need a minimum of an organic-vapor fitted respirator and powered ventilation to apply the foam safely.

In general, foam insulations burn and create toxic smoke. Sometimes they must be covered by an ignition barrier of a thermal barrier when installed in attics and crawl spaces.

Foams are insect friendly materials that can aid termites in gaining a foothold in wood floor structures. All sources of ground water must be mitigated before applying foam to a foundation. When foam is installed on the outside of foundations, the surrounding soil should be treated with a termiticide. Inside a crawl space, foam should never provide a direct link from the ground to wood materials.

Fire Protection for Closed-Cell Foam

Polyurethane closed-cell foam is combustible, sometimes flammable, and creates toxic smoke when it burns. When sprayed in attics and craw spaces, closed-cell foam must sometimes be covered by an ignition barrier or 15-minute thermal barrier.

Ignition barrier materials like galvanized steel and plywood are readily available and so is drywall, the most common 15-minute thermal barrier. However these materials aren't practical as coverings for most spray-foam applications. Intumescent paint is a proprietary latex coating designed to protect foam insulation from flames and heat and is a practical alternative to rigid materials like drywall.

Fire protection requirements vary among foam formulations, according to the amount and type of fire retardant. Foam manufacturers now have at least two formulations: normal and fire-resistant. The more fire-resistant type of closed-cell foam doesn't require an ignition barrier or a thermal barrier in most code jurisdictions.

Code jurisdictions and individual building officials vary in their interpretation of the IRC and other building codes with reference to plastic foams. Check with your local building officials before using closed-cell foam for fire-rated building assemblies.

Open- and Closed-Cell Polyurethane Spray Foam and Injectable Foam

Polyurethane open-cell foam is installed at about 0.5 pcf and achieves an R-value of around 3.7 per inch. Newer formulations are available in densities of around 1.0 pcf with an R-value of around 4.7 per inch. Open-cell foam is available in a highly expansive spray formulation and a less expansive injectable formulation. Neither of these formulations is currently approved by DOE as an insulation or an air-sealing material.

The formulation is injected through a hole, one inch or smaller, through an injection nozzle and not a fill tube. (The plastic fill tube would clog and is not cleanable.) The closed-cell foam can subject a wall cavity to a lot of pressure, so evaluate wall-cladding strength before injecting it.

Polyurethane closed-cell foam, although the most expensive insulation discussed here, is a good value when space is limited, where an air vapor barrier is required, or where its structural strength and durability is needed. Polyurethane closed-cell foam is hazardous to installers and requires special personal protective equipment.

Polyurethane closed-cell foam typically installs at approximately 2 pcf density and achieves an R-value of 6 or more per inch. However, roofing applications call for a density near 3 pcf. Closed-cell foam is an air barrier and a vapor barrier.

Polyurethane open-cell foam has little structural strength. It can be trimmed to eliminate protruding excess from open wall cavities. Polyurethane open-cell foam is not a vapor barrier and is more porous to airflow than the closed-cell foam. It is difficult to install in deep cavities without creating voids.

Open-cell foam can absorb water vapor and liquid water. It can become a medium for mold growth. Don't use open-cell foam in crawl spaces unless proper drainage and ventilation have prevented ground moisture from being a problem.

Polyurethane open-cell foam is less flammable than similar closed-cell formulations but still creates toxic smoke when it burns and is a hazard to installers.

Air Krete Injectable Foam

Air Krete is a proprietary, low-expansion, non-toxic, and non-combustible insulation installed at around 1 pcf with an R-value of about 4.0 per inch. It is used when non-combustible insulation is required. It is water soluble and can be injected through a fill tube.

Tripolymer Injectable Foam

Tripolymer is a proprietary, low-expansion injectable foam installed at around 1.2 pcf at an R-value of 5.1 per inch. The material has very low flammability and smoke generation during a fire. It is widely used to insulate hollow masonry walls. It is water soluble and can be injected through a fill tube.

Expanded Polystyrene (EPS) Foam Board

EPS foam board, sometimes called beadboard, is the most economical of the foam insulations. EPS varies in density from 1 to 2 pcf with R-values per inch of 3.9 to 4.7, increasing with increasing density. EPS is packaged in a wide variety of products by local manufacturers, including structural insulated panels (SIPS), tapered flat-roof insulation, EPS bonded to drywall, and EPS embedded with fastening strips.

EPS is flammable and produces toxic smoke when burned. It has a low maximum operating temperature (160 degrees F) that is a concern for using EPS under dark-colored roofing or siding.

EPS is very moisture resistant and its vapor permeability is in the same order of magnitude as concrete, which makes EPS a good insulation for masonry walls.

Dense EPS (2 pcf) is appropriate for use below grade with weatherproof coverings to prevent degradation by ultraviolet light and freezing and thawing at ground level.

Extruded Polystyrene Foam (XPS) Board

XPS is produced by only a few manufacturers and is popular for below-grade applications. XPS is more expensive than EPS and has an R-value of 5.0 per inch. XPS may be the most moisture-resistant of the foam boards.

XPS is flammable and produces toxic smoke when burned. XPS must be covered by a thermal barrier when installed in living spaces. It has a low operating temperature (160 degrees F) that is a concern for using EPS under shingles or dark-colored siding. XPS must be protected from UV radiation and freezing and thawing at ground level.

Polyisocyanurate (PIC) Foam Board

PIC board has the highest R-value per inch (R-6 to R-7) of any common foam board. PIC is packaged with a vapor permeable or foil (vapor impermeable) facing. PIC is expensive but worth the cost when the depth of an insulation installation is limited.

PIC is combustible and produces toxic smoke during a fire. However some products have fire retardants that allow installation in attics and crawl spaces without ignition barriers. PIC has a low maximum operating temperature (<200 degrees F) that is a concern for using PIC under dark-colored roofing or siding.

Polystyrene Beads

Polystyrene (EPS) beads can be poured or blown into cavities. The cavities must be airtight or the beads will escape, making an annoying mess. EPS beads have an R-value between 2.2 and 2.5 per inch. They work well for filling hollow masonry walls.

Vermiculite and Perlite

These expanded minerals are pourable and used when a non-combustible insulation or high temperature insulation is needed. R-value per inch is between 2.0 and 2.7 per inch. These products are good for insulation around single-wall chimney liners to prevent condensation in the liner.

6.2 Insulation Safety and Durability

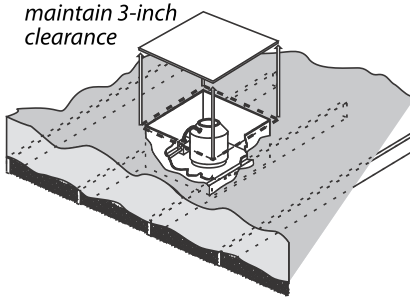
Insulation activities require awareness about safety. Reference the following safety-related sections of this guide as appropriate.

- *See "Moisture Problems" on page 290.*
- *See "Worker Health and Safety" on page 304.*
- *See "Lead-Safe Procedures" on page 311.*

6.2.1 Fire Safety

The following fire-safety and durability issues are particularly important to installing insulation. A home's fire safety must be considered when air sealing, insulating, and all other related energy measures and repairs.

- Install non-insulating insulation shields around heat-producing devices like recessed light fixtures (not labeled IC). Fasten the shields securely to the ceiling so they don't collapse. Maintain 3 inches of clearance between the insulation and the fixture on the sides and top.
- Use only non-combustible insulation to cover the top of insulation shields surrounding non-IC-rated fixtures.



Recessed light fixtures: Covering recessed light fixtures with fire-resistant drywall or sheet-metal enclosures reduces air leakage and allows installers to safely insulate around the box.

- Fibrous insulation may surround and contact IC-rated fixtures (IC = insulation contact). However, spray foam insulation must not surround and contact IC-rated fixtures or any heat-producing fixtures.
- Install non-combustible insulation shields around masonry chimneys, B-vent chimneys, L-vent chimneys, and all-fuel chimneys to keep insulation at least 3 inches away from these chimneys.
- A non-combustible insulation or the listing of the vent material may allow either a smaller clearance than 3 inches or no clearance between insulation and the previously mentioned types of chimneys.
- Foam insulation requires a thermal barrier covering of at least half-inch drywall when installed in a living space. Foam may also require a thermal barrier or ignition barrier when installed in attics or crawl spaces. A *thermal barrier* is a material that protects combustible materials behind it from heat during a fire. An *ignition barrier* is designed to delay the ignition of the material it protects. Ignition barri-

ers include plywood, galvanized steel, damp-spray fiberglass, and intumescent paint. Intumescent paint is a proprietary latex coating designed to protect foam insulation from flames and heat.

6.2.2 Insulation Durability

Moisture is the most common and severe durability problem in insulated building assemblies. Moisture fosters rot by insects and microbes. Entrained moisture reduces the thermal resistance of many insulation materials. Moisture affects the chemistry of some building materials.

Moisture prevention includes denying moisture access to building cavities, allowing condensed water to drain out, and allowing moisture to dry to the indoors, outdoors, or both.

Retrofitting insulation can affect the preventive measures listed here. Consider the function and relevance of these building components whenever you install insulation.

- **Air barrier:** Air can carry moisture into building cavities from indoors or outdoors where the moisture can condense and dampen insulation and other building materials. Air leakage is an energy problem too. The air barrier is any continuous material or building assembly that provides acceptable resistance to Air Leakage.
- **Vapor barrier:** Vapor diffusion can carry large amounts of water vapor into building cavities where it can condense and dampen insulation and other building materials. Vapor barriers prevent water vapor from indoors from diffusing into cavities where condensation can wet insulation and other building materials in cold climates. Cold climates have large differences in humidity between indoors and outdoors that can push vapor through building cavities.
- **Ground-moisture barrier:** The ground under a building is the most potent source of moisture in many buildings, especially those built on crawl spaces. Most crawl spaces

require ground-moisture barriers to prevent the ground from being a major cause of moisture problems.

- **Water resistive barrier (WRB):** Asphalt paper or house wrap, under siding and roofing, serves as the home's last defense to wind-driven rain, which can dampen sheathing and other building materials. This water resistive barrier must be protected during insulation and incorporated into window openings during window replacement.
- **Vapor permeable materials:** Most common building materials are permeable to water vapor, which allows the water vapor to follow a gradient from wet to dry. This process allows building assembles to dry out to either the indoors and outdoors and is the hallmark of fail-safe building assemblies in most climates.
- **Flashings:** Seams and penetrations in building assemblies are protected by flashings, which prevent water from entering these vulnerable areas.
- **Drainage features:** Intentional or unintentional drainage features of buildings allow water to drain out of cavities. Examples: Masonry veneers have intentional drainage planes and weep openings near their bottoms. Cathedral ceilings drain water out through their soffit vents unintentionally.
- **Water storage:** Masonry veneers and structural masonry walls have the ability to store rainwater and dry out during dry weather.
- **Ventilation:** Roofs, attics, crawl spaces and even some walls have ventilation features that dry out wet building assemblies.
- **Termiticide:** When foam insulation is installed below grade, apply a termiticide to the soil in amounts determined by the labeling of the termiticide.

Consult with experts when necessary to preserve, protect, or install these moisture-prevention features, as appropriate according to local climate and established best practices.

6.3 Attic and Roof Insulation

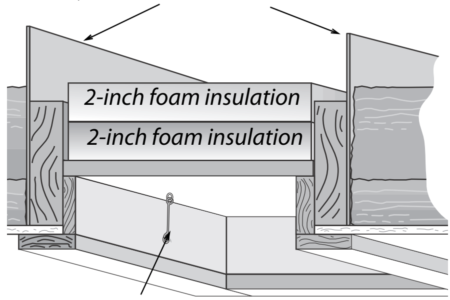
Attic insulation is one of the most cost-effective energy conservation measures available.

6.3.1 Preparing for Attic Insulation

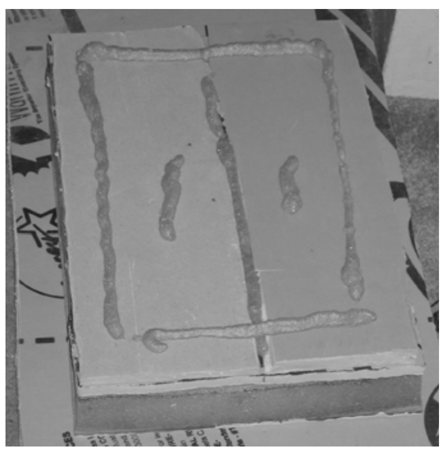
Perform these preparatory steps before installing attic insulation.

- Before insulating the attic, seal air leaks and bypasses as described previously. Air leakage and convection can significantly degrade the thermal resistance of attic insulation. If attic air leaks are not properly sealed, increasing attic ventilation may increase the home's Air Leakage rate. *See "Major Air Leak Locations & Treatments" on page 111.*
- Repair roof leaks and remove other large moisture sources and repair other attic-related moisture problems before insulating attic. If attic-related moisture problems can't be repaired, don't insulate the attic.
- Vent all kitchen and bath fans outdoors through appropriate roof fittings, side wall fittings, or soffit fittings. Use galvanized steel vent pipe, and insulate the pipe to prevent condensation. Avoid using flexible plastic or aluminum duct because these materials restrict airflow. Check all fans for proper back-draft damper operation. Repair or replace the damper or the entire fan assembly if the damper doesn't operate freely.

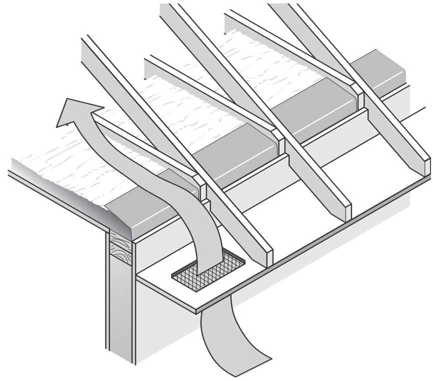
- Install an attic access hatch if none is present. The attic hatch should be at least 22 inches on each side if possible. Insulate the hatch to R-30. **Note:** Do not cut framing member to install a hatch without approval from a local agency or a structural engineer.
- When using blown type insulation build an insulation dam around the attic access hatch. Build the dam with rigid materials like plywood or oriented-strand board so that the dam supports the weight of a person entering or leaving the attic.



Insulated attic hatch: Building a dam prevents loose-fill insulation from falling down the hatchway. Foam insulation prevents the access hatch from being a thermal weakness. Install foam to achieve attic-insulation R-value or at least R-30. Foam can be glued together in layers.



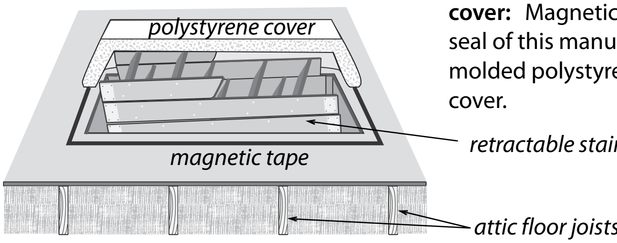
- Install vent chutes, baffles, tubes, or other devices to prevent insulation from plugging air channels between soffit vents and the attic. Baffles, chutes etc. should be installed in every joist or truss bay to ensure no insulations enters the soffit area. These devices should maximize the amount of insulation that may be installed over top plates without clogging ventilation paths. They also help prevent the wind-washing of insulation caused by cold air entering soffit vents.



Soffit chute or dam: Allows installation of maximum amount of insulation in this cold area. Also prevents wind washing and airway blockage by insulation.

Insulating & Sealing Retractable Attic Stairways

Retractable attic stairways are sometimes installed above the access hatch. Building an insulated box or buying a manufactured stair-and-hatchway cover are good solutions to insulating and sealing this weak point in the thermal boundary.



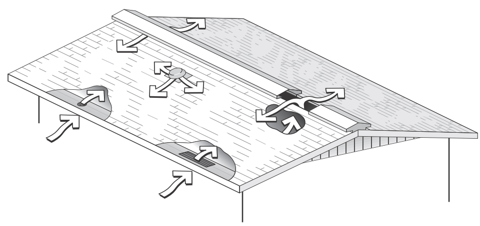
Manufactured retractable-stair cover: Magnetic tape forms the seal of this manufactured molded polystyrene insulated cover.

6.3.2 Attic Ventilation

Attic ventilation is intended to remove moisture from the attic during the heating season and/or to remove solar heat from the attic during the cooling season. Evaluate attic ventilation according to the 2009 International Residential Code (IRC) which states the following.

- ✓ A maximum ratio of one square foot of net free area to 150 square feet of attic area.
- ✓ With an interior vapor barrier or with distributed ventilation (high and low), only one square foot of vent per 300 square feet of attic area is required.

Retrofitting additional attic ventilation won't cure a moisture problem caused by airborne moisture migrating up from the living space. Instead, preventing moisture from entering the attic is the best way to keep attic insulation dry. Ceilings should be thoroughly air sealed to prevent moist indoor air from leaking through the ceiling.



Low and high attic ventilation: Distributed ventilation — high and low — is more effective than vents that aren't distributed.

Power Attic Ventilators

Power ventilators have limited value in reducing air conditioning cost and can consume a lot of electricity themselves. These appliances are not permitted under the Tennessee WAP plan and should not be installed. Many of these fans run much longer than they are needed, counteracting any benefit they may provide. Power ventilators can also depressurize attics, increasing air leakage through the ceiling.

6.3.3 Blowing Attic Insulation

Install attic insulation to R38, depending upon existing insulation level. Air sealing attics must precede attic insulation and this may require removing existing insulation and debris that currently prevents effective air sealing. *See "Removing Insulation for Air Sealing" on page 110.*

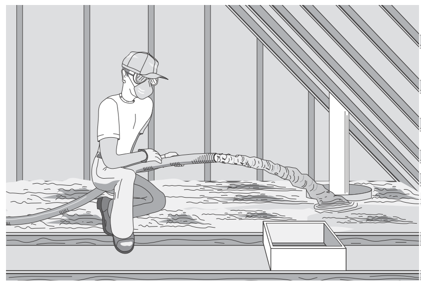
Blown insulation is usually preferable to batt insulation because blown insulation forms a seamless blanket. Attic insulation always settles: cellulose usually settles 10% to 20% and fiberglass settles 3% to 10%. Blowing attic insulation at the highest achievable density helps minimize settling while minimizing air moment within the insulation.

Follow these specifications when installing loose-fill attic insulation.

- ✓ Calculate how many bags of insulation are needed to achieve the R-value specified on the bag's label. *See "Calculating Attic Insulation" on page 322.*
- ✓ Maintain a high density by moving as much insulation as possible through the hose with the available air pressure. The more the insulation is packed together in the blowing hose, the greater is the insulation's density.
- ✓ When filling a tight eaves space, snake the hose out to the edge of the ceiling. Allow the insulation to fill and pack before pulling the hose back towards you. The eave area is the home's largest thermal bridge and it's important to put as much insulation into the eaves as possible, even if a little insulation spills into the soffit. The baffles provide the air space for ventilation.
- ✓ Fill the edges of the attic first, near the eaves or gable end, and move toward the center.
- ✓ Install insulation at a consistent depth. Level the insulation with a stick if necessary.

- ✓ Install insulation depth rulers: one for every 300 square feet.
- ✓ Post an insulation certificate near the attic entrance to facilitate inspection.
- ✓ Before installing insulation, flag junction boxes so they can be identified after being covered.

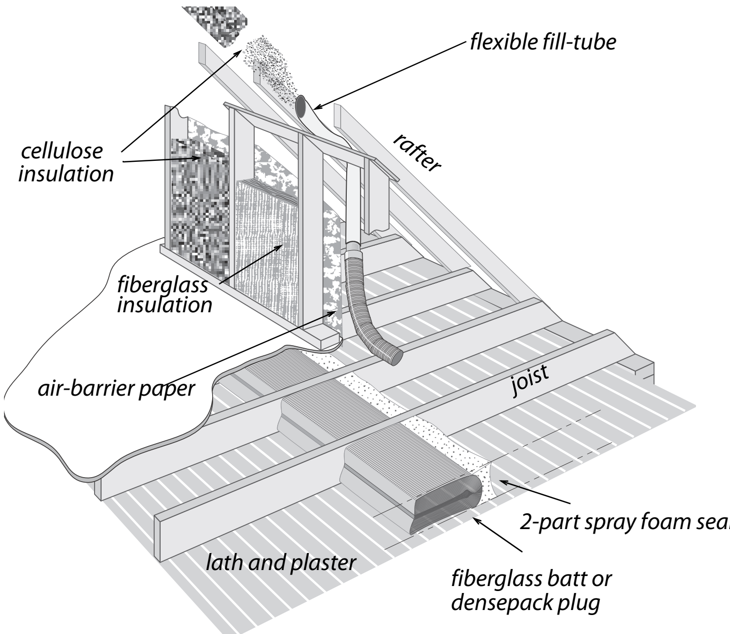
Blown-in attic insulation: Blown insulation is more continuous than batts and produces better coverage. Insulation should be blown at a high density to minimize settling and air convection.



6.3.4 Installing Attic Batt Insulation

Follow these specifications when installing fiberglass batts in an attic.

- ✓ Install unfaced fiberglass insulation whenever possible. Faced insulation doesn't tend to lay as flat as un-faced batts, and the facing is not very effective in slowing vapor movement because most of the vapor movement happens with air migration.
- ✓ If you must install faced batts, install them with the facing toward the heated space. Never install faced insulation over existing insulation.
- ✓ Cut batts carefully to ensure a tight fit against the ceiling joists and other framing.



Finished attic best practices: Air sealing and insulation combine to dramatically reduce heat transmission and air leakage in homes with finished attics.

6.3.5 Finished Knee Wall Attics

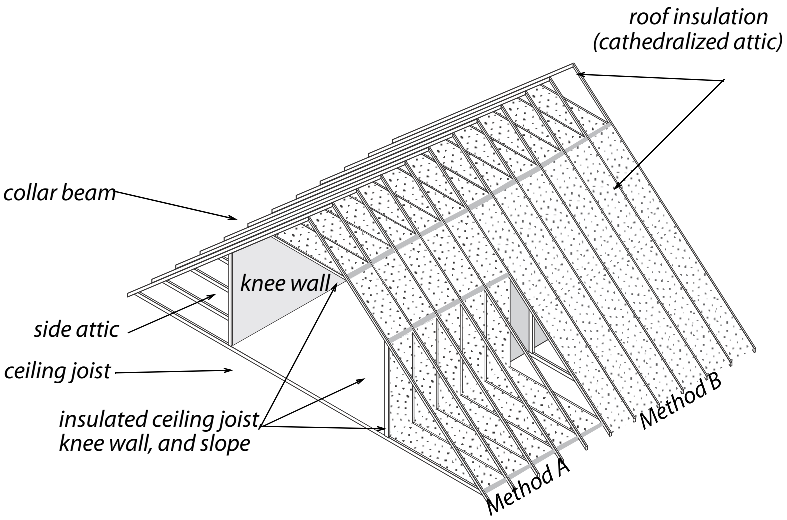
Finished attics require special care when installing insulation. They often include five separate sections that require different sealing and insulating methods.

1. Exterior end walls
2. Collar-beam attic
3. Sloped roof
4. Outer ceiling joists of the side attic
5. Knee walls

Seal air leaks in all these assemblies before insulating them. If necessary, remove the planking and insulation from the side-attic floor to expose the air leaks.

Follow these specifications when insulating finished attics.

- Seal large air leaks between conditioned and non-conditioned spaces. *See "Air Sealing Homes" on page 99.*
- Inspect the structure to confirm that it has the strength to support the weight of the insulation.
- Insulate access hatches to the approximate R-value of the assembly through which it is located.



Finished attic: There are two approaches to insulating a finished attic. Either A) insulate the knee wall and side attic floor, or B) insulate the roof deck.

Exterior Walls of Finished Attic

Insulate these walls as described in *"Wall Insulation" on page 146*.

Collar-Beam Attic

Insulate this type of half-story attic as described in *"Perform these preparatory steps before installing attic insulation." on page 135*.

Sloped Roof

Insulate sloped roof with densepack fiberglass insulation. Install plugs of fiberglass batt, or other vapor permeable material, at the ends of this cavity to contain the blown insulation while allowing it to breathe.

Side Attic: Outer Ceiling Joists

Insulate this small attic as described in *"Perform these preparatory steps before installing attic insulation." on page 135*. If this attic has a floor, remove one or more pieces of flooring to access the cavity and blow fiberglass or cellulose insulation to a medium pack.

Knee Walls

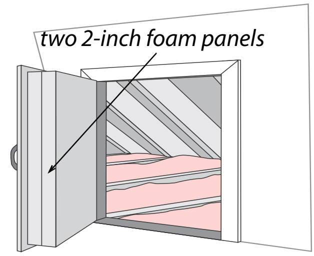
Insulate knee walls using any of the following methods.

- Install un-faced fiberglass batts and cover the insulation with house wrap on the attic side.
- Install the house wrap first and blow fibrous insulation into the cavity through the house wrap.
- Spray the cavities with open-cell or closed-cell polyurethane foam.

To seal and insulate under the knee wall, create an airtight and structurally strong seal in the joist space under the knee wall. This can be done by inserting 2-inch-thick foam sheets and foaming their perimeters with one-part or two-part foam, or by inserting a fiberglass batt into the cavity and foaming its face with an inch or two-part closed-cell spray foam.

For kneewall hatches, observe the following.

- Insulate knee-wall access hatches and collar-beam access hatch with 3 or more inches of rigid-foam insulation. Or install a fiberglass batt or batts wrapped with house wrap stapled to the hatch door.
- Weatherstrip the hatch and provide a positive closure.



Insulated access door in knee wall: Try to achieve at least R-15, or the highest R-value practical.

6.3.6 Walk-Up Stairways and Doors

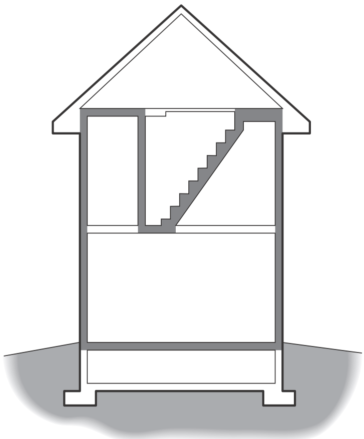
Think carefully about how to establish a continuous insulation and air barrier around or over the top of an attic stairway. If the attic is accessed by a stairwell and standard vertical door, you can blow dense pack fibrous insulation into walls of the stairwell. Install a threshold or door sweep, and weatherstrip the door. Also, blow packed cellulose insulation into the cavity beneath the stair treads and risers.

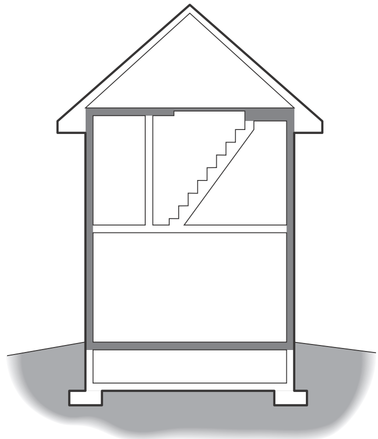
You can also establish the thermal boundary at the ceiling level, but this requires a horizontal hatch at the top of the stairs.

When planning to insulate stairwells, investigate barriers such as fire blocking that might prevent insulation from filling cavities you want to fill, and consider what passageways may lead to other areas you don't want to fill such as closets. Balloon-framed walls and deep stair cavities complicate this measure.

Insulating & Sealing Retractable Attic Stairways

Retractable attic stairways are sometimes installed above the access hatch. Building an insulated box or buying a manufactured stair-and-hatchway cover are good solutions to insulating and sealing this weak point in the thermal boundary.

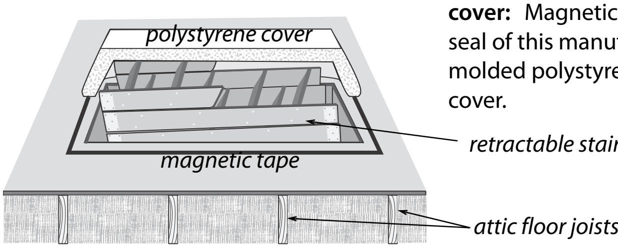




Insulating and sealing attic stair walls, doors, and stairs: Insulating and air sealing these is one way of establishing the thermal boundary.

Insulating and weatherstripping the attic hatch: Air sealing around the hatch is an alternative way of establishing the thermal boundary.

Manufactured retractable-stair cover: Magnetic tape forms the seal of this manufactured molded polystyrene insulated cover.



6.4 Wall Insulation

If you find the existing walls uninsulated or partially insulated, add insulation to provide complete coverage for all the home's exterior walls.

Install wall-cavity insulation with a uniform coverage and density. Wall cavities encourage airflow like chimneys. Convection currents or air leakage can significantly reduce wall insulation's thermal performance if channels remain for air to migrate or convect.

In general, insulation specialists over-estimate the R-value of walls. Thermal bridging at studs, plates, and window and door framing along with poor installation can take up to 50 percent off the nominal value of the wall-cavity insulation.

The thermal bridging problem, in particular, may require installing foam sheathing under existing or new siding to cope with future energy costs.

Blown Wall-Insulation Types

Cellulose, fiberglass, and open-cell polyurethane foam are the leading insulation products for retrofit-installation into walls.

Table 6-1: Wall Insulation Density and R-Value per Inch

Insulation Material	Density	R-Value/in.
Fiberglass (virgin fiber)	2.2 pcf	4.1
Cellulose	3.5 pcf	3.4
Open-cell urethane foam	0.5 pcf	3.8
Tripolymer	1.2 pcf	5.1
Air Krete	2.1 pcf	3.9

pcf = pounds per cubic foot; psf = pounds per square foot
* For a 2-by-4 wall cavity

6.4.1 Preparing for Retrofit Wall Insulation

Inspect and repair walls thoroughly to avoid damaging the walls, blowing insulation into unwanted areas, or causing a hazard.

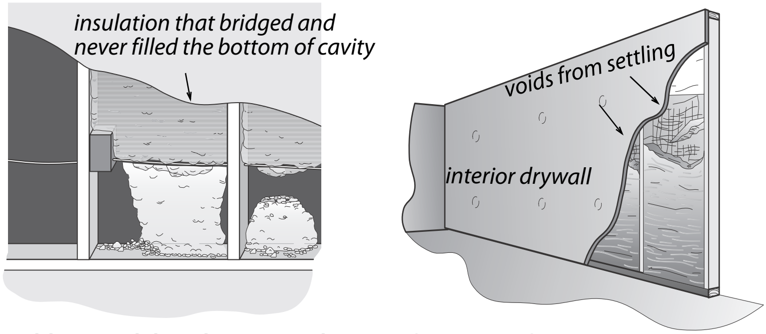
Inspecting and Repairing Walls

Before starting to blow insulation into walls, take the following preparatory steps.

- ✓ Calculate how many bags of insulation are needed to achieve the R-value specified on the bag's label. *See "Calculating Wall Insulation" on page 326.*
- ✓ Inspect walls for evidence of moisture damage. If condition of the siding, sheathing, or interior wall finish indicates an existing moisture problem, no sidewall insulation should be installed until the moisture problem has been identified and corrected.
- ✓ Seal gaps in external window trim and other areas that may admit rain water into the wall.
- ✓ Inspect indoor surfaces of exterior walls to assure that they are strong enough to withstand the force of insulation blowing. Reinforce siding and sheathing as necessary.
- ✓ Inspect for interior openings from which insulation may escape such as balloon framing openings in the attic or crawl space, pocket doors, un-backed cabinets, interior soffits, openings around pipes under sinks, and closets. Seal openings as necessary to prevent insulation from escaping.
- ✓ Confirm that exterior wall cavities aren't used as return or supply ducts. Avoid these cavities, or re-route the ducting.
- ✓ Ensure that electrical circuits contained within walls aren't overloaded. Maximum ampacity for 14-gauge copper wire is 15 amps and for 12-gauge copper wire is 20 amps. Install S-type fuses where appropriate to prevent circuit overloading. Don't insulate cavities containing knob-and-tube insulation. *See "Electrical Safety" on page 303.*

Drilling Exterior Sheathing: Insulation Retrofit

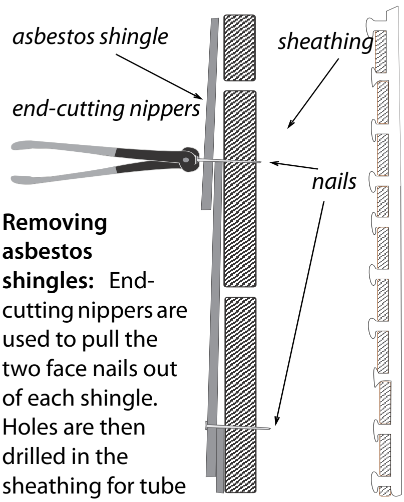
Avoid drilling through siding. Where possible, carefully remove siding and drill through sheathing. This avoids the potential lead-paint hazard of drilling the siding. It also makes it easier to insert flexible fill tubes since the holes pass through one less layer of material.



Problems with low density insulation: Blowing insulation through one or two small holes usually creates voids inside the wall cavity. This is because insulation won't reliably blow at an adequate density more than about one foot from the nozzle. Use tube-filling methods whenever possible, using a 1.5-inch hose inserted through a 2-inch or larger hole.

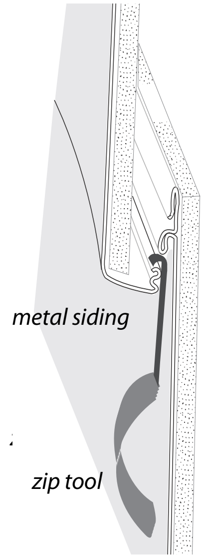
If the siding cannot be removed, consider drilling the walls from inside the home. Obtain the owner's permission before doing so, and practice lead-safe weatherization procedures. *See page 311.*

- ✓ Asbestos shingles may be carefully removed by pulling the nails holding them to the sheathing or else nipping off the nailheads. Dampening the asbestos tiles keeps dust down. Refer to your company standards for proper protective equipment when working with asbestos materials.
- ✓ Metal or vinyl siding may be removed using a zip tool.
- ✓ Homes with brick veneer or blind-nailed asbestos siding may be insulated from the inside. Holes drilled for insulation must be returned to an appearance as close to original as possible, or so they are satisfactory to the customer.



Removing asbestos shingles: End-cutting nippers are used to pull the two face nails out of each shingle. Holes are then drilled in the sheathing for tube filling.

Removing metal siding: A zip tool separates joints in metal siding.



6.4.2 Retrofit Closed-Cavity Wall Insulation

This section describes three ways of installing wall insulation.

- ✓ Blowing walls with fibrous insulation using a fill tube from indoors or outdoors.
- ✓ Blowing walls with fibrous insulation from indoors or outdoors using a directional nozzle.
- ✓ Installing batts in an open wall cavity.

Installing Retrofit Fibrous Wall Insulation

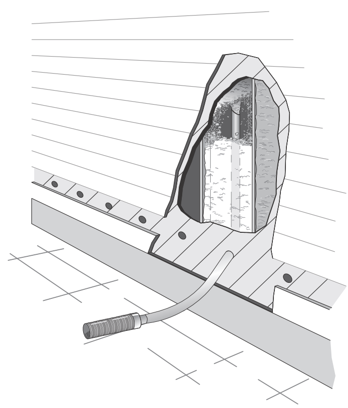
Two methods for installing sidewall insulation are commonly used: tube-fill method (one large hole) or the multi-hole method, using a directional nozzle. The tube-fill method is preferred because it requires only one hole, and it ensures that the wall achieves an adequate coverage and density of blown insulation.

Blowing Walls with a Fill-Tube

Dense-pack wall insulation is best installed using a blower equipped with separate controls for air and material feed.Mark the fill tube in one-foot intervals to help the installer verify when the tube has reached the top of the wall cavity.

Tube-filling walls: This method can be accomplished from inside or outside the home. It is the preferred wall insulation method because it is a reliable way to achieve a uniform coverage and density.

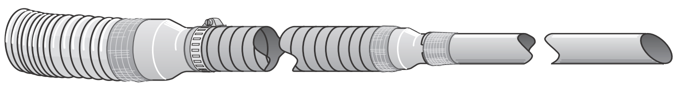
To prevent settling, cellulose insulation must be blown to at least 3.5 pounds per cubic foot (pcf) density. Fiberglass dense-pack must be 2.2 pcf and the fiberglass material must be designed for dense-pack installation. Blowing fibrous insulation this densely requires using a fill tube.



Insulate walls by this procedure.

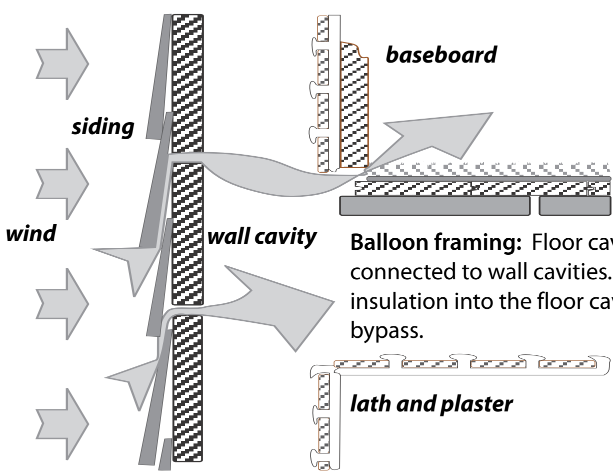
1. Drill 2-to-3-inch diameter holes to access stud cavity.
2. Probe all wall cavities through holes, as you fill them with the fill tube, to identify fire blocking, diagonal bracing, and other obstacles. After probing and filling, drill whatever additional holes are necessary to ensure complete coverage.
3. Start with several full-height, unobstructed wall cavities so you can measure the insulation density and calibrate the blower. An 8-foot cavity (2-by-4 on 16-inch centers) should consume a minimum of 10 pounds of cellulose.

4. Insert the hose all the way to the top of the cavity. Start the machine, and back the hose out slowly as the cavity fills.
5. Then fill the bottom of the cavity in the same way.
6. Learn to use the blower control to achieve a dense pack near the hole while limiting spillage.
7. Seal and plug the holes, repair the weather barrier, and replace the siding.



Insulation hoses, fittings, and the fill tube: Smooth, gradual transitions are important to the free flow of insulation.

When insulating balloon-framed walls, try to blow an insulation plug into each floor cavity to insulate the perimeter between the two floors. This also seals the floor cavity so it does not become a conduit for air migration. If the process is requiring too much insulation, try placing a plastic bag over the end of the fill tube and blowing the insulation into the plastic bag. The bag will limit the amount of insulation it takes to plug this area.



Balloon framing: Floor cavities are usually connected to wall cavities. Blow a plug of insulation into the floor cavity to seal this bypass.

Multi-Hole Blowing Method for Fibrous Insulation

The multi-hole method is often used when the insulator doesn't want to remove siding. The multi-hole method is the least preferable wall-insulation method because it often results in voids and sub-standard density. It is sometimes used effectively in conjunction with tube-filling to fill small cavities around doors or windows.

If you do employ this method, use a powerful blowing machine — a model designed for professional insulators.

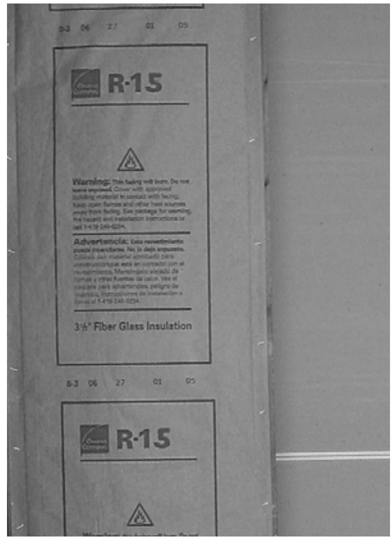
- Drill holes into each stud cavity large enough to admit a directional nozzle. The holes should be spaced so that the insulation is blown no more than 12 inches upward or 24 inches downward.
- Probe wall cavities to determine location of obstacles and nature of cavities around window and door areas.
- All wall cavities around windows and doors should be filled with insulation.
- Seal all holes with wood or plastic plugs.

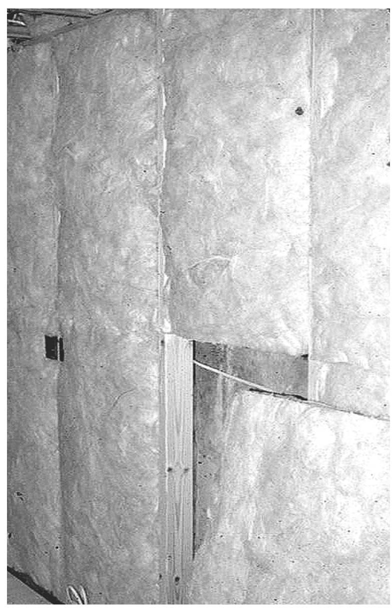
Directional nozzle: It's difficult to achieve the correct density with the multi-hole method because the density decreases as the distance from the nozzle increases.

6.4.3 Open-Cavity Wall Insulation

Fiberglass batts are the most common open-cavity wall insulation. They achieve their rated R-value only when installed carefully. If there are gaps between the cavity and batt at the top and bottom, the R-value can be reduced by as much as 30 percent. The batt should fill the entire cavity without spaces in corners or edges.

- Use unfaced friction-fit batt insulation where possible. Fluff the batts during installation to fill entire wall cavity.
- Seal all significant cracks and gaps in the wall structure before or after the insulation is installed.
- Staple faced insulation to outside face of studs on the warm side of the cavity. Don't staple the facing to the side of the studs, even though drywallers may prefer that method, since it leaves an air space that encourages convection currents.
- Cut batt insulation to the exact length of the cavity. A too-short batt creates air spaces above and beneath

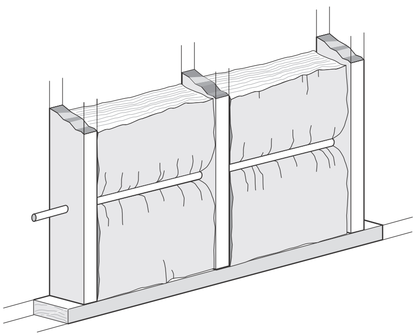




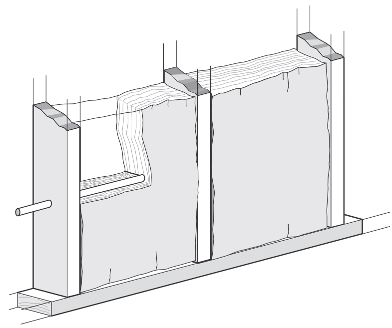
Un-faced fiberglass batts: Install batts in open walls and attach them to the face of the stud as shown here. Or install unfaced batts. Either way, the batts should be accurately cut and carefully installed.

the batt, allowing convection. A too-long batt will bunch up, creating air pockets.

- Split batt around wiring, rather than letting the wiring bunch the batt to one side of the cavity.
- Insulate behind and around obstacles with scrap pieces of batt before installing batt.
- Fiberglass insulation exposed to the interior living space must be covered with minimum half-inch drywall or other material that has an ASTM flame spread rating of 25 or less.



Fiberglass batts, compressed by a cable: This reduces the wall's R-value by creating a void between the insulation and interior wallboard.



Batt, split around a cable: The batt attains its rated R-value.

6.5 Floor and Foundation Insulation

Floor and foundation insulation and air sealing complete the thermal boundary at the base of the building. This consideration is simply missing in many homes. In heating climates, floor and/or foundation insulation is a key part of improving the thermal performance of homes.

In homes with heated and occupied basements, the best choice is to insulate and air seal the basement walls, and so include the basement within the thermal boundary. The choice is less straightforward in homes with unused basements or crawl spaces where a choice must be made between insulating the floor or the foundation walls. This decision should be made according to cost-effectiveness and other factors as discussed in *"Decisions about Basements and Crawl Spaces" on page 91*.

To establish an effective thermal boundary, the insulation and air barrier should be adjacent to each other. Establishing an effective air barrier — comparable to the air barriers in the above-grade walls and ceiling — may be difficult. Furthermore, foundation or floor insulation may or may not be cost-effective or practical, considering the home's weatherization budget and potential moisture problems.

6.5.1 Preparing for Floor or Foundation Insulation

Floor and foundation insulation can increase the likelihood of moisture problems. Installers and home owners should take all necessary steps to prevent moisture problems from ground moisture sources.

Moisture Source-Reduction

Observe the following specifications for avoiding the deteriorating effects of crawl-space and basement moisture on insulation and other building materials.

- ✓ Solve all drainage problems, ground-water problems, wood-deterioration, and structural problems before installing floor or foundation insulation.
- ✓ Slope the ground outside the home away from the foundation.
- ✓ Install gutters and downspouts in wet locations and direct roof water away from the home.
- ✓ Install a ground-moisture barrier in all dirt-floored crawl spaces.
- ✓ Confirm that all combustion vents (chimneys), clothes-dryer vents, and exhaust fan vents are vented to outdoors.

- ✓ Suggest a sump pump for crawl spaces or basements with a history of flooding. The sump pump should be located in an area where it will collect water from the entire below-grade area and pump it to a drain or swale outdoors away from the foundation.

Ground Moisture Barrier

The ground is neither an air barrier nor a moisture barrier and can transport air-and-moisture into a crawl space. Crawl-space moisture can lead to condensation, mold, and rot. Air passing through the soil can also contain radon and pesticides. Covering the ground with a moisture barrier seals out most moisture and soil gases.

Cover the ground completely with an moisture barrier such as 6 mil polyethylene, installed without voids or gaps. Overlap moisture barrier at least 12 inches at joints. Seal the seams in the ground moisture barrier with construction tape or acoustical sealant, making it a air-moisture barrier.

Extend moisture barrier up foundation wall a minimum of 6 inches and fasten it with polyurethane adhesive or acoustical sealant to the masonry wall. Wood furring strips may also be used to secure moisture barrier to the wall, following the application of the adhesive between the wall and moisture barrier. Ground moisture barrier should extend 6 inches up all interior piers and be attached with polyurethane adhesive or acoustical sealant.

Keep the plastic sheeting at least 3 inches away from any wood construction material. Ground moisture barriers aren't a solution to standing water and should not be installed until the source of the standing water has been identified and corrected.

Naturally Ventilated Crawl Spaces

When insulating the floor, the crawl space is usually ventilated naturally through passive vents. A ground moisture barrier is required to protect the floor insulation and other building materials throughout the home from moisture.

In a crawl space with a correctly installed ground-moisture barrier, ventilation openings could be minimized to one square foot of net free ventilation area for every 1500 square feet of crawlspace floor area with vents to provide cross ventilation, according to the 2009 IRC.

Cover ventilation openings with quarter-inch hardware cloth or an equivalent corrosion-resistant material. Locate new vents within 3 feet of the corners of the crawl space.

Rim Insulation and Air Sealing

The joist spaces at the perimeter of the floor are a major weak point in the air barrier and insulation. Insulating and air sealing both the rim joist and longitudinal box joist are appropriate either as individual procedures or as part of floor or foundation insulation.

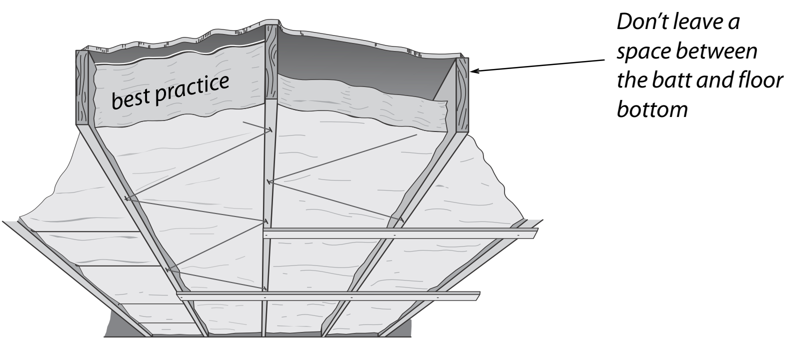
Air-seal stud cavities in balloon-framed homes as a part of insulating the rim joist. Air seal other penetrations through the rim before insulating. Two-part spray foam is the most versatile air sealing and insulation system for the rim joist because spray foam air seals and insulates in one step. Polystyrene or polyurethane rigid board insulation are also good for insulating and air sealing the rim joist area. When the rim joist runs parallel to the foundation wall, the cavity may be air sealed and insulated with methods similar to those as shown here.

Don't use fiberglass batts to insulate rim joist areas because air can circulate around the fiberglass, causing condensation and encouraging mold on the cold rim joist. Foam-insulated rim joists are not an approved ECM in Tennessee; however, all joints between the floor joists, band joist and subfloor around the perimeter of the foundation are to be sealed to prevent air infiltration.

Installing Batt Floor Insulation

Observe the following specifications for insulating under floors.

1. Seal all significant air leaks through the floor before insulating the floor, using strong airtight materials.
2. Use batt insulation. Batts should be in continuous contact with the subfloor.
3. Batts must either fill the complete depth of each cavity or have a thermal resistance of at least R-19.
4. Batts must be neatly installed, fitting tightly together at joints, fitting closely around obstructions, and filling all the space within the floor cavity.
5. Fasteners for floor insulation must resist gravity, the weight of insulation, and moisture condensation.



Floor insulating with batts: Use unfaced fiberglass batts, installed flush to the floor bottom, to insulate floors. The batt should fill the whole cavity if it is supported by lath or plastic twine underneath. For batts that don't fill the whole cavity, use wire insulation supports.

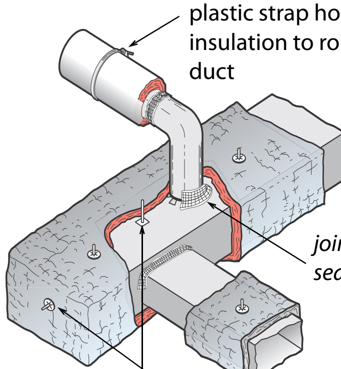
Crawl-Space Access Doors

Crawlspace access doors, adjacent to a conditioned space, must be insulated to at least R-19 for horizontal openings and to at least R-13 for vertical openings. Crawlspace access doors must be effectively weatherstripped.

6.6 Duct Insulation

Insulate supply ducts that run through unconditioned areas outside the thermal boundary such as crawl spaces, attics, and attached garages with a minimum of R-6 vinyl- or foil-faced duct insulation. Don't insulate ducts that run through conditioned areas unless they cause overheating in winter or condensation in summer. Follow the best practices listed below for installing insulation.

- ✓ Always perform duct sealing before insulating ducts.
- ✓ Duct-insulation R-value must meet or exceed IECC 2009 standards: R-8 for vented attics, R-6 for other areas.
- ✓ Insulation should cover all exposed supply ducts.
- ✓ Insulation's compressed thickness must be more than 75% of its uncompressed thickness. Don't compress duct insulation excessively at corner bends.
- ✓ Fasten insulation using mechanical means such as stick pins, twine, staples, or plastic straps. Tape is essential for covering joints in the insulation to prevent air convection and the condensation that could result from convection. However, tape often fails as a supporting material if expected to resist the force of the insulation's compression or weight.



Duct insulation: Supply ducts, located in unheated areas, should be insulated to R-8 for ventilated attics and R-6 for other areas.

Caution: Burying ducts in attic insulation is a common practice in some regions and clearly reduces energy losses from ducts. However, burying ducts in attic insulation can cause condensation on ducts in humid climates.

Chapter 7: Windows and Doors

This chapter presents specifications and procedures for improving the energy performance of windows and doors. Detailed specifications for window replacement provide guidance on this often-performed and potentially troublesome retrofit.

Windows and doors are a major concern to homeowners and energy specialists alike. Windows and doors were once thought to be a major air-leakage problem. However, the widespread use of blower doors has shown that windows and doors don't tend to harbor large air leaks. But the combined heat losses and gains, by conduction, convection, radiation, and air leakage through windows are usually very significant.

Unfortunately, the square-foot cost to improve windows is high, so the payback from window improvements is usually not as attractive as many other building-shell retrofits. In older buildings, though, the windows and doors may be in such poor condition that repair or replacement is essential to a building's survival even if it's not an energy-saving priority. However, window and door replacement is not permissible with WAP Health and Safety funds.

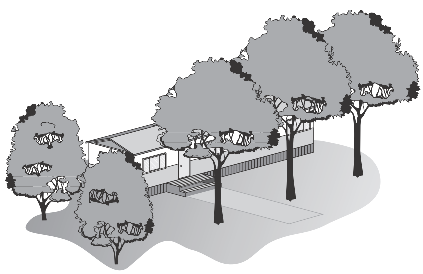
All tasks relating to window and door improvement, repair, and replacement should be accomplished using lead-safe weatherization methods. *See "Lead-Safe Procedures" on page 311.*

Landscaping for Shade

Trees and bushes can provide shade for windows, walls, and roofs. Trees also cool the air around the home with shade and moisture evaporating from their leaves. Well-planned landscaping can reduce an un-shaded home's air conditioning costs by up to 50% while adding value to the home. Consider solar water heating and photovoltaic electricity before developing a landscaping plan.

The best plan for cool landscaping includes tall deciduous trees on the south side of the home to block high mid-day sun. Shorter trees or bushes on the east and west block morning and afternoon sun. Keep bushes far enough away from the foundation so that watering doesn't cause moisture problems.

Plant deciduous trees that lose their leaves in the autumn to admit winter sun. Choose types that are quick-growing and easy to care for in your region. Check with a local nurseryman to determine the best varieties of trees, when to plant, and the planting method.



Trees for shade: Landscaping is a good long-term investment for residences. Tall deciduous trees on the south block high summer sun while allowing lower winter sun to reach the home. Shorter trees or bushes provide protection from low-angle sun on the east and west.

7.1 Storm Windows

A storm window is an additional window installed outside or inside the primary window.

7.1.1 Exterior Aluminum Storm Windows

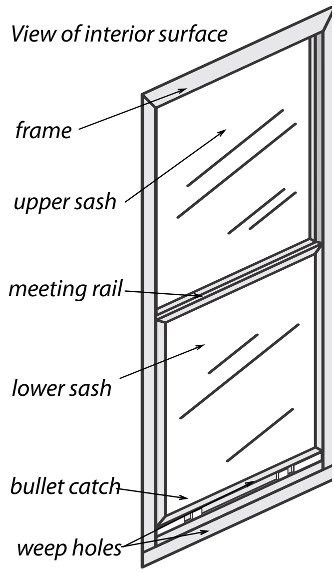
Storm windows are less expensive than window replacement. Storm windows can preserve old worn primary windows from more destructive weathering.

Aluminum storm windows are the best choice if they are well designed and installed properly

- ✓ Frames should have sturdy corners so they don't rack out-of-square during transport and installation.
- ✓ Sashes must fit tightly in their frames.

- ✓ The gasket sealing the glass should surround the glass's edge.
- ✓ The storm window should be sized correctly and fit tightly in the opening.

The installation of storm windows should follow these guidelines.



Aluminum exterior storm windows: They protect the primary window and add about an R-1 to the window assembly.

- ✓ Don't install new storm windows to replace existing storms if the existing storms are in good condition or can be repaired at a reasonable cost.
- ✓ Caulk storm windows around the frame at time of installation, except for weep holes at the bottom that must not be sealed. If weep holes are not manufactured into new storm window, they should be drilled.
- ✓ Don't allow storm windows to restrict emergency egress or ventilation through moveable windows. Choose windows that are openable from the inside, or install pin-on storm sashes that open along with the moveable primary window.

See also "Mobile home double window" on page 278.

7.2 Window Repair and Air Leakage Reduction

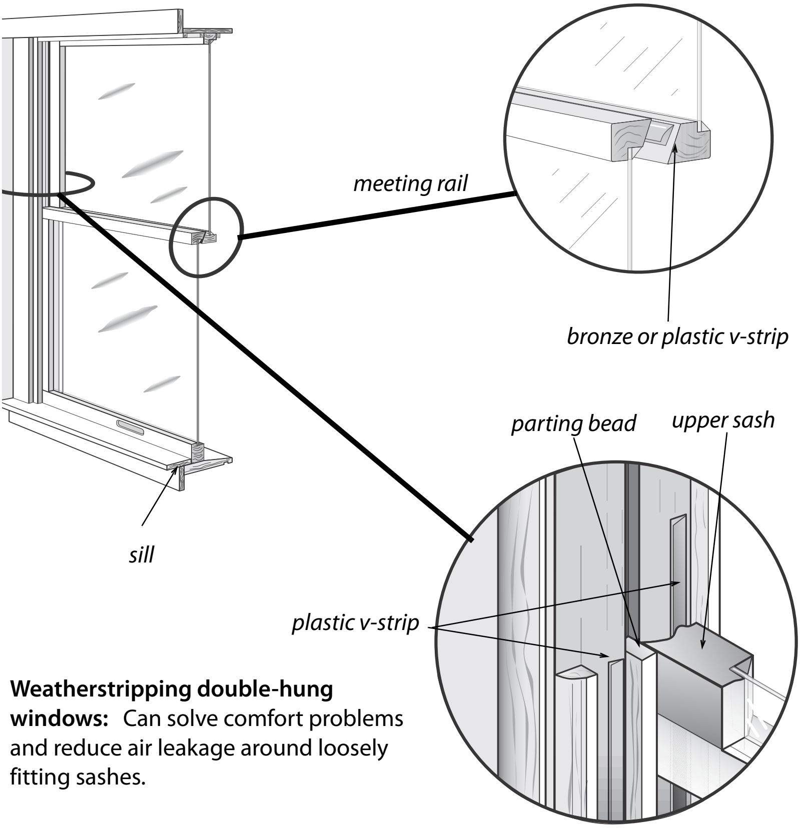
With the exception of broken glass or missing window panes, windows are rarely the major source of air leakage in a home.

Window weatherstripping is typically not cost-effective but may be installed to solve a comfort problem. Avoid expensive or time-consuming window repair measures that are implemented to solve minor comfort complaints.

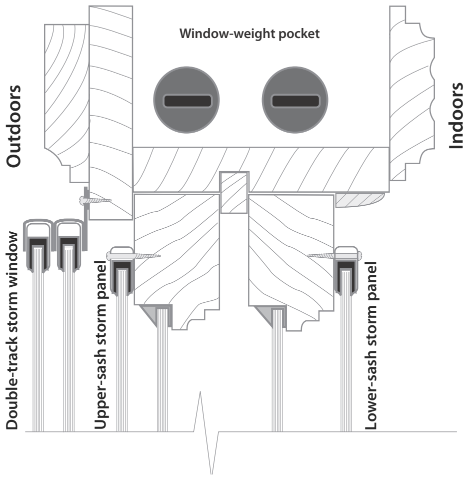
Re-glazing window sashes is time consuming, and is best accomplished as part of a comprehensive window rehabilitation project. Re-glazing wood windows may not be a durable repair without thorough scraping, priming, and painting. Repair measures may include the following measures.

- ✓ Replace missing or broken glass. Use glazing compound and glazier points when replacing glass in older windows. Glass cracks that are not noticeably separated should be ignored.
- ✓ Caulk interior and exterior window frame to prevent air leakage, condensation, and rain leakage. Use sealants with rated adhesion and joint movement characteristics appropriate for both the window frame and the building materials surrounding the window.
- ✓ Replace missing or severely deteriorated window frame components. Extremely damaged wood should filled with a marine epoxy, primed, and painted.
- ✓ Adjust window stops if large gaps exist between stop and jamb. Ensure that the window operates smoothly following stop adjustment.
- ✓ Weatherstrip large gaps between the sash and the sill or stops. Weatherstrip the meeting rails if needed.
- ✓ Replace or repair missing or non-functional top and side sash locks, hinges, or other hardware if such action will significantly reduce air leakage.

Use lead-safe work practices when working on windows. *See page 311.*



Weatherstripping double-hung windows: Can solve comfort problems and reduce air leakage around loosely fitting sashes.



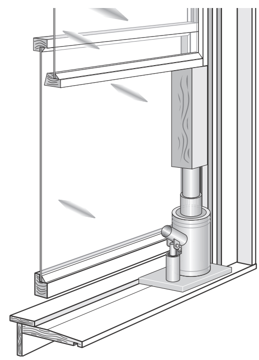
Optimized double-hung window: An exterior aluminum storm window plus storm window panels on the window sashes create triple glazing in this double-hung window.

Weatherstripping Double-Hung Windows

Wooden double-hung windows are fairly easy to weatherstrip. Keep in mind, window weatherstripping is mainly a comfort retrofit and a low weatherization priority.

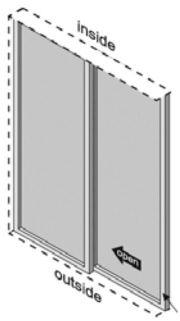
Paint is the primary obstacle when weatherstripping double-hung windows. Often the upper sash has slipped down, and is locked in place by layers of paint, producing a leaking gap between the meeting rails of the upper and lower sashes.

- ✓ To make the meeting rails meet again, either break the paint seal and push the upper sash up, or cut the bottom of the lower sash off to bring it down.
- ✓ To lift the upper sash, cut the paint around its inside and outside perimeter. Use leverage or a small hydraulic jack to lift the sash. Jack only at the corners of the sash. Lifting in the middle will likely break the window.
- ✓ Block, screw, or nail the repositioned upper sash into place.

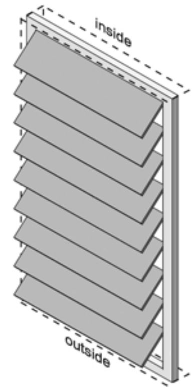


Lifting an upper window sash: First cut paint away from around the sash inside and outside. Then lift with leverage or a jack.

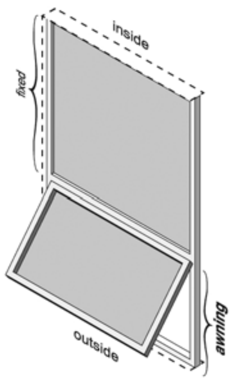
- ✓ To weatherstrip the window, you must remove the lower sash. Cut the paint where the window stop meets the jamb so the paint doesn't pop off in large flakes as you pry the stop off. Removing one stop is sufficient to remove the bottom sash.
- ✓ Scrape excess paint from the sashes and the window sill. You may need to plane the sides so the window operates smoothly.
- ✓ Apply vinyl V-strip to the side jambs, and bronze V-strip to the meeting rail on the top sash. The point of the bronze V goes skyward. The weatherstrip is caulked on its back side and stapled in place, as shown on *page 165*.



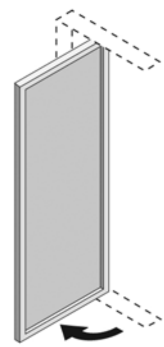
Horizontal Slider



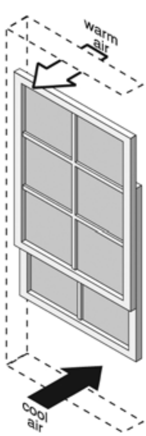
Jalousie



Awning



Casement



Double Hung

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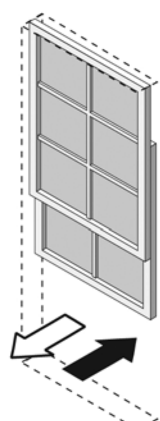


Single Hung

7.3 WINDOW REPLACEMENT SPECIFICATIONS

The purpose of these specifications is to guide the selection and installation of replacement windows. Improper window installation can cause air leakage, sound leakage, and water leakage

Existing window openings may have moisture damage and air leakage. These conditions require repair during the window replacement process.

Auditors and Contractors must use RRP & LSW methods to ensure occupants and workers are not placed at risk during window repair measures.

Included here are specifications for two special window safety considerations.

1. Windows in high risk areas, such as around doors and walkways, must have safety glass.
2. Windows are part of fire escape planning for homes, so this egress function must be recognized and accommodated.

7.3.1 Window Replacement Options

Window replacements are generally not cost-effective energy conservation measures. Replace windows only as emergency-repair measures when the window is missing, or damaged beyond repair, or found to be cost-effective.

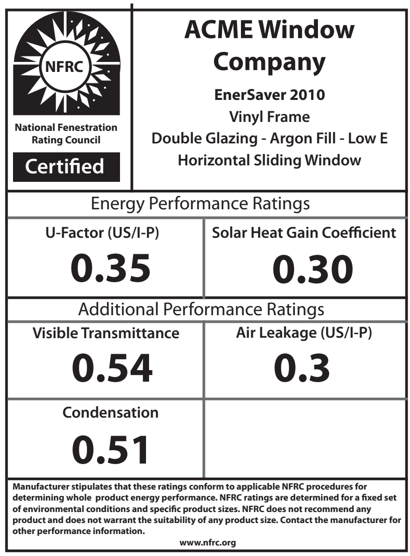
Replacement windows should have a window unit U-value of 0.35 or less as rated by the National Fenestration Rating Council (NFRC) or approved equal.

7.3.2 Window Energy Specifications

Installing new windows incurs a large labor expense so they should be as energy-efficient as budget allows.

1. Replacement windows must have a U-factor less than or equal to U-0.35. Lower is better, especially in cold climates.

2. Replacement windows facing east or west in air conditioned homes should have a solar heat-gain coefficient (SHGC) of less than or equal to 0.30. Lower is better, especially in hot climates.



NFRC label: The key selection criteria for window shopping is displayed on the NFRC label.

3. Consider advanced window designs with triple glazing, insulated frames and sashes, gas fillings between the glass panes, and less conductive spacers between the glass panes.

Window Accessory Specifications

Accessories are extra components used by installers to attach the window, seal the window into the home's water resistive barrier, and complete the window installation.

1. Windows must be shimmed as necessary using flat shims of the correct thickness to give the proper support at the sill.

2. All fasteners used for window installation must be corrosion resistant, according to ASTM B 633, B 766, or B456.

3. Flashing for new windows must be reinforced, coated flexible flashing, designed for exterior water protection.
4. Sealants should be compatible with the materials they seal.
5. In joints more than $^{3}/_{16}$ inch in width, backer rod must be used to control sealant depth and prevent three-sided adhesion by the caulking.
6. All sides of exterior wood, used in the installation, must be primed with exterior primer or other equivalent wood sealer.
7. Metal window components must be protected from dissimilar metals or corrosive materials.

7.3.3 Removing Old Windows

Existing windows should be removed without damaging the home's interior finish, siding, exterior trim, and the water resistive barrier.

1. Protect the interior of the home from construction debris.
2. Remove window sashes, jambs, and/or siding, depending on the window-replacement method chosen.
3. Repair moisture damage to the rough opening before installing the new window.
4. Follow manufacturer's installation instructions.

7.3.4 Installing Replacement Windows

The most important considerations for installing new windows is that the window installation is weathertight and airtight.

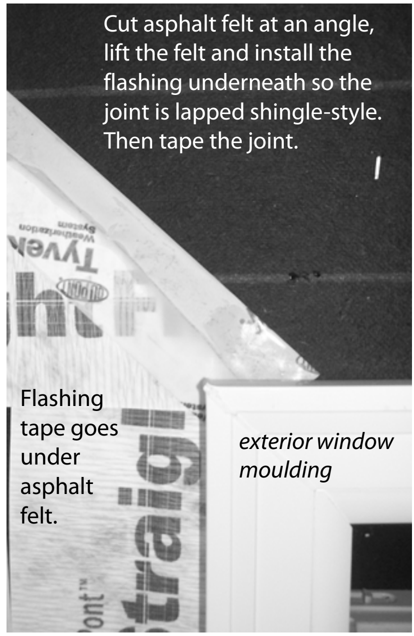
Water leakage is a serious concern because it deteriorates building components around the window. To prevent water leakage in frame buildings, the window must be carefully integrated into the home's water resistive barrier (WRB). A frame home's WRB is a waterproof breathable membrane that stops rain water penetration through the siding from dampening the sheathing underneath. The integration of the new window and existing WRB is achieved using special tapes or adhesive flexible flashing.

Installing Windows within the Rough Opening

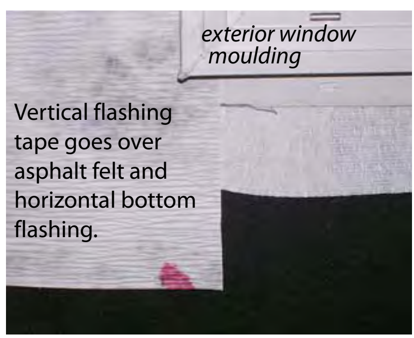
Remove the existing window, window jambs, sill, and exterior trim. If the entire house is not re-sided at the same time, the nearby siding may need to be removed to allow proper installation of flashing. Then install the replacement window in the rough opening in a similar manner as new construction.

1. Use whatever shimming assembly is necessary including flat shims, a shimmed flat sill, or a sill pan to support the replacement window on a solid, level, and water-resistant sill surface. The window's weight should not be supported by the flanges.
2. Flash the new window around its perimeter with approved flashing. Install the flashing from bottom to top (like roof shingles) so water cannot enter the wall.
3. At the top of the window, fit the window's flange **underneath** the home's water-resistive barrier. At the sides and bottom,

Top Flashing Detail



Bottom Flashing Detail



Window flashing details: Install window flashing shingle-style, carefully incorporating the flashing into the wall's weather-resistive barrier.

fit the flange **between** the siding and the water-resistive barrier.

4. Install caulking or butyl putty tape on the window flange before installing the window. Follow the manufacturer's recommendations on sealant and its application.
5. When using caulking as the window sealant, the window must be installed immediately after caulking application before the caulking becomes contaminated or forms a skin.
6. Use fasteners with heads wide enough in diameter to span the holes or slots in the window flange.
7. Avoid over-driving the fasteners or otherwise deforming the window flange.
8. Air seal the space between the window frame and the rough opening, or between the old window jambs and sill. Use one-part foam or foam backer rod with caulking. Merely stuffing this gap with fiberglass insulation doesn't create an effective air seal.
9. Windows that are exposed to wind-driven rain or without overhangs above them should have a rigid cap flashing to prevent rainwater from draining onto the window. The cap flashing should overlap the sides of the window enough to divert water away from vertical joints bordering the window.

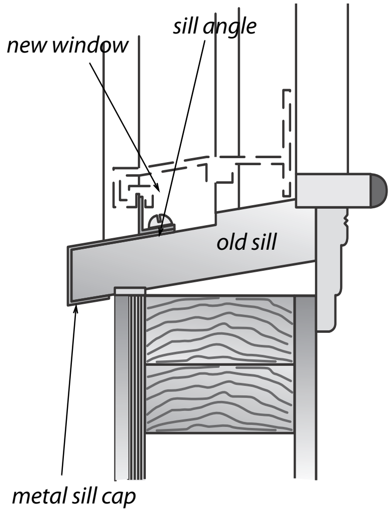
Installing Replacement Windows: Existing Jambs and Sill

Flashing an existing window frame: Wrap the water-resistant barrier from the outside to the interior of the window frame so that any penetrating moisture will drain out without soaking into the wood.

When the contractor is confident about the condition of the existing rough framing, jambs, and sill, replacement windows are often installed without stripping the assembly out to the rough frame. Air sealing will be more difficult and probably less effective than when the entire assembly is rebuilt.

1. Install flat shims to provide a level surface to support under the vertical structural members of the new window frame. The window should not be supported by the flanges.
2. Protect the existing sill with metal and plastic flashing if necessary for drainage and to protect the protruding wood sill.
3. Seal the replacement window to a continuous stop during installation.
4. Use correctly sized shims where the side jambs of the replacement window are fastened into the side jambs of the old window.

5. Seal the space between the new window frame and old window frame with one-part foam.



Replacement window and sill angle: The sill angle supports the window level and the sill cap covers and protects the aged sill.

7.4 Window Safety Specifications

Windows have special requirements for breakage-resistance in areas that are prone to glass breakage, and for fire escape in bedrooms. This safety information is included here because of the difficulty of obtaining it elsewhere.

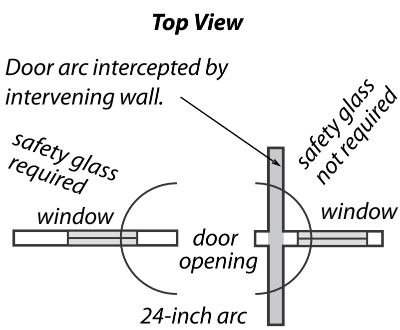
7.4.1 Windows Requiring Safety Glass

Safety glass must be either laminated glass or tempered glass bearing a permanent label identifying it as safety glass.

Instead of safety glazing, glazed panels may have a protective bar installed on the accessible sides of the glazing 34 to 38 inches above the floor. The bar shall be capable of withstanding a horizontal load of 50 pounds per linear foot without contacting the glass and be a minimum of $1^1/_2$ inches in width.

Safety glass or a protective bar is required in the following conditions.

- ✓ Glazing wider than 3 inches in entrance doors.
- ✓ Glazing in fixed and sliding panels of sliding doors and panels in swinging doors other than wardrobe doors.
- ✓ Glazing in fixed or operable panels adjacent to a door where the nearest exposed edge of the glazing is within a 24-inch arc of the vertical edge of the door in a closed position and where the bottom edge of the glazing is less than 60-inches above the floor or walking surface unless there is an intervening wall or permanent barrier between the door and the glazing.

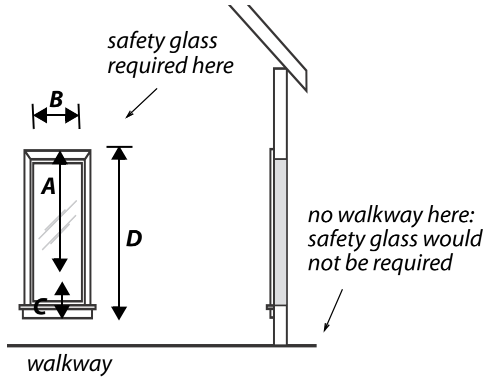


Safety glass around doors: A window near a door must be glazed with safety glass when the window is less then 24 inches from the door and less than 60 inches from the floor.

✓ Glazing in any portion of a building wall enclosing showers, hot tubs, whirlpools, saunas, steam rooms, and bathtubs where the bottom exposed edge is less than 5 feet above a standing surface or drain inlet.

Glazing in an individual fixed or operable panel that meets all of the following conditions must also have safety glass:

1. An exposed area of an individual pane greater than 9 square feet, and
2. An exposed bottom edge less than 18 inches above the floor.
3. An exposed top edge greater than 36 inches above the floor.
4. One or more walkways within 36 inches horizontally of the glazing.



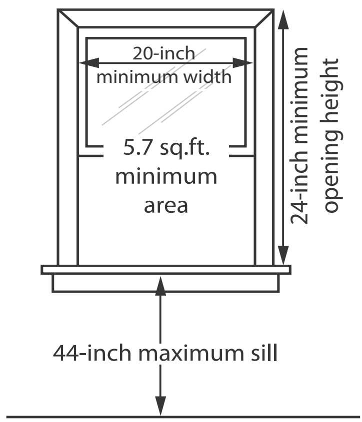
A x B = greater than 9 ft^2, and
C = less than 18 inches from floor, and
D = more than 36 inches from floor.

Large windows near walking surfaces: Safety glass is required in picture windows with a nearby walkway.

7.4.2 Fire Egress Windows

Windows are the designated fire escape for many homes and should offer a minimum opening for a person's escape from a fire. The following specifications must be observed when replacing windows, regardless of the compliance of existing windows with fire-egress specifications.

1. Windows installed in bedrooms must observe the specifications for egress windows described here.
2. Each bedroom must have one egress window.
3. Egress windows must provide an opening that is at least 20 inches wide and at least 24 inches high.
4. Egress windows must provide an opening with a clear area of at least 5.7 square feet.
5. The finished sill of the egress window must be no higher off the floor than 44 inches.



Egress windows: Windows for fire escape must be large enough and a convenient distance from the floor.

6. According to the 2009 IRC, you may install security bars, screens, or covers over egress windows as long as these security devices are easily removable from indoors. Purchasing or installing these security devices may not be paid for with WAP funds.

7.5 Door Replacement and Repair

Doors suffer a lot of wear because of their jobs as entrances for buildings. Doors need repair when they are damaged and replacement when repair costs exceed the cost of a new insulated door.

Install flashing around doorways according to the specifications in *"Installing Replacement Windows" on page 170*.

7.5.1 Door Replacement

Door replacements are rarely cost-effective energy conservation measures. Replace a door as an emergency-repair, when the door is damaged beyond repair. Tight uninsulated doors in good condition should not be replaced. Auditors and Contractors must use RRP & LSW methods to ensure occupants and workers are not placed at risk during door repair measures. Observe the following standards when replacing exterior doors.

- All replacement doors must be an exterior-grade foam core doors.
- Replace the door using an insulated door-blank or a pre-hung steel insulated door.
- Replacing an exterior panel door with another panel door is not allowed.
- All replacement doors must have three hinges.
- Replacement door should not have glass panes. However, the installation of a door viewer is permissible.

7.5.2 Door Repair and Improvement

Doors have a small surface area and their air leakage is more of a localized comfort problem than a significant energy problem most of the time. However, door operation affects building security and durability, so doors are often an important repair priority.

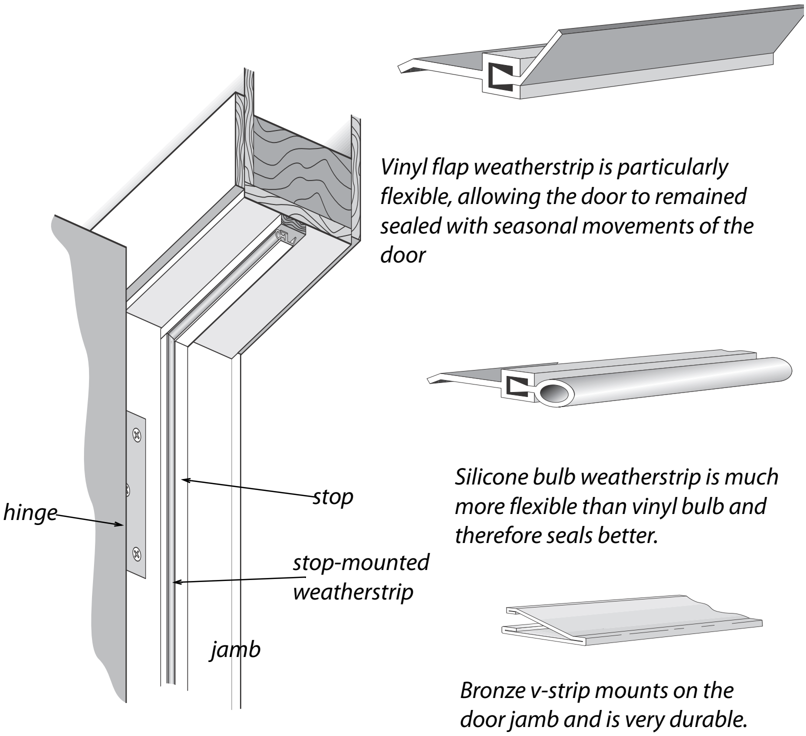
Door repair improves home security and building durability. Door repair can also save energy if the door currently has a poor fit.

Door weatherstrip, thresholds and sweeps are marginally cost effective. These measures may be used only if they are found to be cost effective.

- ✓ Tighten door hardware and adjust stops so door closes snugly against its stops.
- ✓ Use a durable stop-mounted or jamb-mounted weatherstrip material to weatherstrip the door. New weatherstrip must form a tight seal with no buckling or gaps when installed.
- ✓ Plane or adjust the door so it closes without rubbing or binding on the stops and jambs, especially in homes that may have lead paint.
- ✓ Install thresholds and door sweeps if needed to prevent air leakage. These air seals should not bind the door. Thresholds should be caulked on both sides at the sill and jamb junction.
- ✓ Replace missing or inoperable lock sets.
- ✓ Reposition the lock set and strike plate.
- ✓ Reposition stops if necessary.
- ✓ Seal gaps between the stop and jamb with caulk.
- ✓ Install a door shoe if needed to repair damage.

If the door binds at the top, check the tightness of screws in the top hinge and tighten them if necessary. If the hinges are tight, check the space between the door and the frame's hinge-side. If there's a $^1/_4$-inch gap between door and frame on the hinge side, you can give $^1/_8$ inch of that gap to the latch side by deepening the mortise — the chiseled-out section of door frame directly under the hinge. If the door is too tight to the hinge side, install one or more pieces of cardboard underneath a hinge.

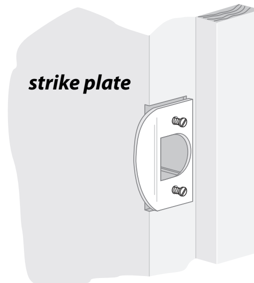
Doors can be adjusted by moving the hinges in or out. Moving the top hinge in moves the door upward and toward the hinge.



Weatherstripping doors: Weatherstripping doors is mainly a comfort retrofit. The door should be repaired before weatherstripping by tightening hinges and latches. The door stop should fit tightly against the door when it is closed.

Moving the top hinge out drops the door down and moves the door away from the hinge.

If a door won't latch, inspect the door stops and weatherstripping to see if they are binding. If there is no obvious problem with the weather-strip or stops, move the strike plate out slightly or use a file to remove a little metal from the strike plate. The strike plate is mortised into the door frame that receives the latch. Use toothpicks or dowels to patch widened screw holes if you have to move the strike plate.



Minor door repair: Tightening and adjusting locksets, strike plates, and hinges helps doors work better and seal tighter.

Chapter 8: Evaluating Heating and Cooling Systems

This chapter specifies energy efficiency improvements to heating and cooling systems.

The most important visual-inspection tasks are covered in this chapter. HVAC technicians should test heating systems for combustion safety and steady state efficiency (SSE) as part of a comprehensive energy audit.

Decisions about air conditioning service or system replacement also depend on testing and visual inspection. HVAC technicians should test cooling systems during routine service work to verify adequate airflow and correct refrigerant charge. Technicians should also adjust, repair, or replace heating systems based on inspection and testing.

Weatherization agencies may replace, repair, or install heating systems in homes with "Red tagged", inoperable, or nonexistent heating systems where the local climate necessitates these actions for occupants' health and safety. Weatherization agencies may replace, repair, or install air conditioning systems using health and safety funds in homes in which occupants are at risk of heat ailments.

Duct leakage should be evaluated for both heating and cooling systems during visual inspecting and testing. Duct sealing must be based on testing.

The inspection and testing procedures in this chapter may go beyond the auditor's training and daily practice. The reason they're included is that installation and service problems are common, and it makes sense for the auditor to be able to specify procedures for HVAC contractors. The better the auditor's understanding, the better the quality control, the better energy savings, comfort, and customer satisfaction. Consider the advanced procedures something to learn about as needed.

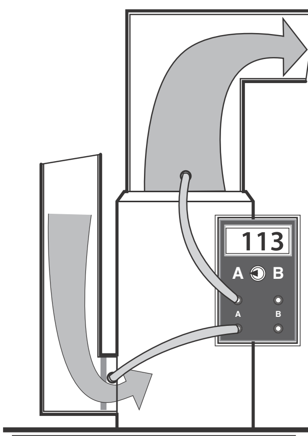
8.1 Heating System Replacement

Here, we discuss replacing furnaces. Then we examine the fuel issues for natural gas.

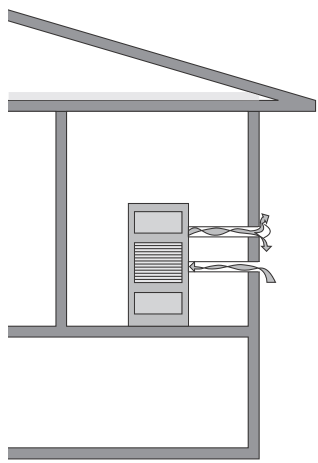
8.1.1 Combustion Furnace Replacement

This section is for the air handlers of combustion furnaces. Successful furnace replacement requires selection of the right furnace, making repairs to ducts and other remaining hardware, and testing to verify that the new furnace is operating correctly.

- Make sure that the furnace is sized correctly, using an accurate methodology such as Manual J.
- Verify that all accessible ducts were sealed as part of installation, from the air handler and plenums to the branch connections.

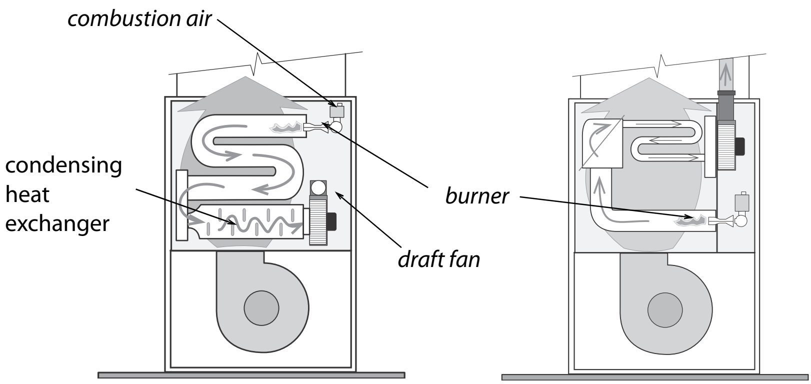


Static pressure and temperature rise: Testing static pressure and temperature rise across the new furnace should verify that the duct system isn't restricted. The correct airflow, specified by the manufacturer, is necessary for high efficiency.



Sealed combustion heaters: Sealed combustion furnaces prevent the air pollution and house depressurization caused by some open combustion heating units.

- If flue gas temperature or supply air temperature are unusually high, check static pressure and fuel input. *See "Ducted Air Distribution" on page 230.*
- Filters should be held firmly in place and provide complete coverage of blower intake or return register. Filters should not permit air to bypass the filter when installed in the return plenum. Filters should be easy to replace.
- Leave the manufacturer's literature including operating manual and service manual with the furnace or heat pump.



90+ Gas furnace: A 90+ furnace has a condensing heat exchanger and a stronger draft fan for pulling combustion gases through its more restrictive heat exchange system and establishing a strong positive draft.

80+ Gas furnace: An 80+ furnace has a restrictive heat exchanger, a draft fan, and has no draft diverter or standing pilot.

Supporting Air Handlers

Support new air handlers using the following specifications.

- Support horizontal air handlers from below with a non-combustible, water-proof, and non-wicking material. Or support the horizontal air handler with angle iron and threaded rod from above.

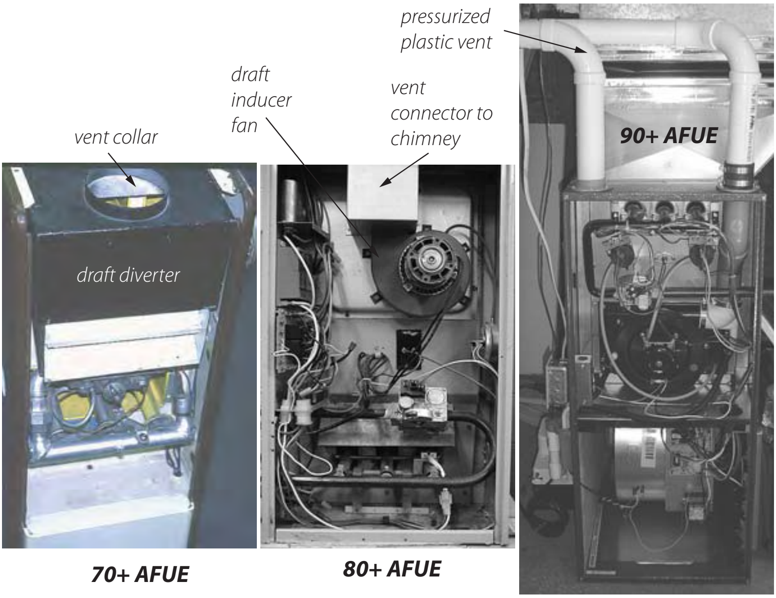
- Support upflow air handlers with a non-flammable material from below when necessary to hold it above damp ground or damp concrete.
- Support downflow air handlers with a airtight supply plenum capable of supporting the air handler's weight. Insulate this supply plenum with rigid duct insulation on the exterior of the plenum.

8.1.2 Gas-Fired Heating Installation

The goal of appliance replacement is to save energy and provide safer heating. The heating replacement project should produce a gas-fired heating system in virtually new condition, even though existing components like the gas lines, chimney, or ducts may remain. Any necessary maintenance or repair on these remaining components must be part of the installation. Any design flaws in the original system should be diagnosed and corrected during the heating-system replacement.

- If cost-effective, select a 90+ AFUE furnace (ENERGY STAR or equivalent) and specify its installation as a sealed-combustion (direct vent) unit.
- Non-condensing furnaces with a minimum AFUE of 80% may be installed if the 90% replacement furnace isn't cost-effective or there isn't any place to drain the condensing furnace's condensate.
- New gas-fired furnaces should be installed with adequate clearances to facilitate maintenance.
- Follow manufacturer's venting instructions along with the NFPA 54 to establish a proper venting system. *See "Inspecting Venting Systems" on page 216.*
- Check clearances of heating unit and its vent connector to nearby combustibles, according to the National Fuel Gas Code (NFPA 54). *See page 216.*

- Clock gas meter to measure gas input and adjust gas input if necessary. *See page 332.*



Gas furnace evolution: Energy auditors should be able to identify the 3 types of gas and propane furnaces. Only the 90+ AFUE furnace has a pressurized vent. The two earlier models vent into traditional atmospheric chimneys.

Testing New Gas-Fired Heating Systems

✓ Perform combustion testing and adjust fuel-air mixture to minimize O_2, without creating CO.

✓ Test the new venting system for CO. *See page 208.*

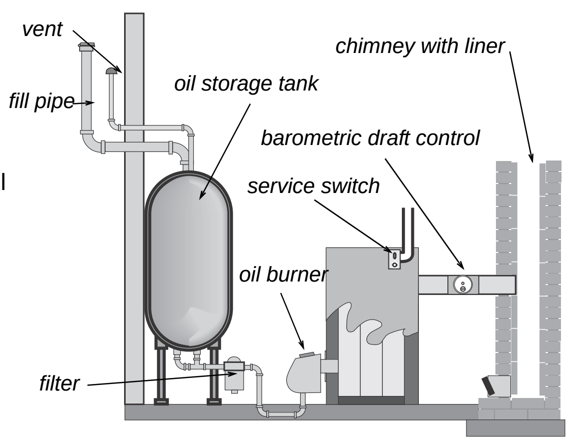
✓ Test gas water heater to insure that it vents properly after installation of a sealed-combustion, 90+ AFUE furnace. Install a chimney liner if necessary to improve water-heater venting.

8.1.3 Oil-Fired Heating Installation

The goal of the system replacement is to save energy and provide safer, more reliable heating. System replacement should provide an oil-fired heating system in virtually new condition, even though components like the oil tank, chimney, piping, or ducts may remain. Any maintenance or repair on these remaining components should be part of the job. Any design flaws related to the original system should be diagnosed and corrected during the heating-system replacement.

- ✓ New oil-fired furnaces should have an AFUE of 83%.
- ✓ New oil-fired furnaces should be installed with adequate clearances to facilitate maintenance.
- ✓ Examine existing chimney and vent connector for suitability as venting for new appliance. The vent connector may need to be re-sized and the chimney may need to be re-lined.

Oil heating system: Components of an oil heating system may need repair and cleaning during replacement of the furnace.

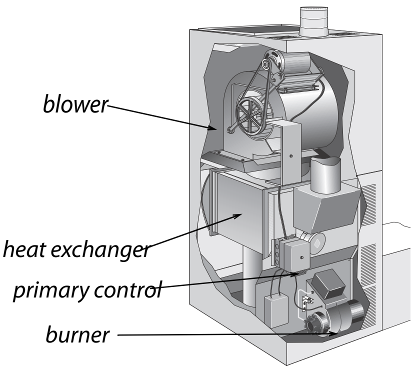


- ✓ Check clearances of heating unit and its vent connector to nearby combustibles, by referring to NFPA 31. See *"Clearances to Combustibles for Vent Connectors" on page 219*.
- ✓ Install new fuel filter and purge fuel lines as part of new installation.

- ✓ Inspect oil tank and remove deposits at bottom of tank.
- ✓ Bring tank and oil lines into compliance with NFPA 31.
- ✓ Verify the presence of working emergency shut-off, installed in the living space.

Testing New Oil-Fired Heating Systems

- ✓ Check for the presence of a control that interrupts power to the burner in the event of a fire.
- ✓ Measure oil pressure and note the nozzle's gallon-per-minute (gpm) rating. Adjust oil pressure or replace nozzle as necessary to achieve correct input. Verify input from oil pressure and nozzle gpm, using nozzle manufacturer's data.
- ✓ Verify correct spray angle and spray pattern.
- ✓ Test transformer voltage to verify compliance with manufacturer's specifications.

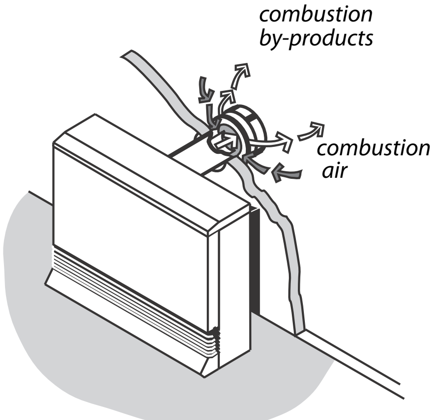


Oil-fired downflow furnaces: Their design hasn't changed much in recent years except for the flame-retention burner.

- ✓ Test control circuit amperage, and adjust thermostat heat anticipator to match. Or follow thermostat manufacturer's instructions for adjusting cycle length.
- ✓ Adjust oxygen, flue-gas temperature, and smoke number to match manufacturer's specifications or specifications given here. Smoke number should be zero on all modern oil-fired equipment.

8.2 GAS SPACE HEATER REPLACEMENT

In homes where duct work is not present space heaters are inherently more efficient than central heaters, because they have no distribution system. As homes become more airtight and better insulated, space heaters become a more practical option for heating the whole home.



Sealed Combustion Space Heater: Sealed combustion space heaters draw combustion air in and exhaust combustion by-products, using a draft fan.

Space Heater Controls: Many modern energy-efficient space heaters have programmable thermostats as standard equipment.

Space heaters are replaced as an energy conservation measure or for health and safety reasons. Use the highest efficiency unit available for the application. Inspect existing space heaters for health and safety problems.

- Follow manufacturer's venting instructions carefully. Don't vent sealed-combustion, induced-draft space heaters into naturally drafting chimneys.
- Verify that flue gas oxygen and temperature are within the ranges specified in *Table 8-3 on page 198.*
- If the space heater sits on a carpeted floor, specify a fire-rated floor protector, sized to the width and length of the space heater, as a base.

- Locate space heater away from traffic, draperies, and furniture.
- Insist that the space heater be provided with a properly grounded duplex receptacle for its electrical service.

8.2.1 Space Heater Operation

Inform the customer of the following operating instructions.

- Don't store any objects near the space heater that would restrict airflow around it.
- Don't use the space heater to dry clothes or for any purpose other than heating the home.
- Don't allow anyone to lean or sit on the space heater.
- Don't spray aerosols near the space heater. Many aerosols are flammable or can cause corrosion to the space heater's heat exchanger.

8.2.2 Unvented Space Heaters

Unvented space heaters are common in some regions of Tennessee. Unvented space heaters include ventless gas fireplaces and gas logs installed in fireplaces designed for wood or coal burning. These unvented space heaters deliver all their products of combustion to the indoors. They are not a safe heating option and should be replaced with vented space heaters. They should not be replaced with electric space heaters.

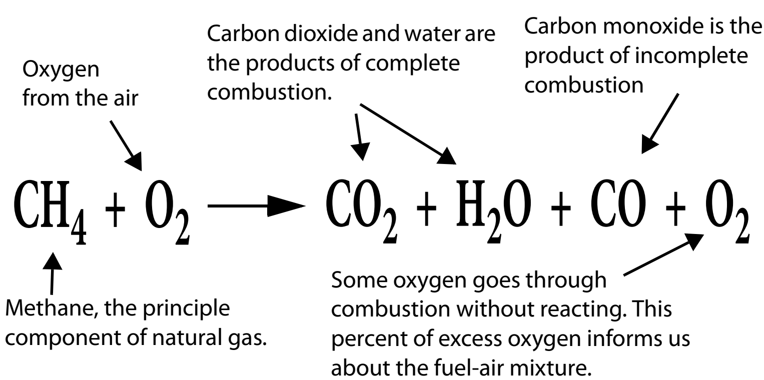
Review the DOE policies on unvented space heaters in WPN 08-4 and WPN 11-6. DOE forbids unvented space heaters as primary heating units in weatherized homes. However, unvented space heaters may be used as secondary heaters, under the following conditions.

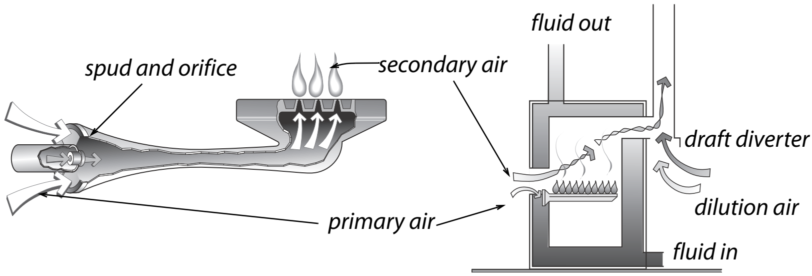
- Must have an input rating less than 40,000 BTUH.
- Must have an input rating less than 6000 BTUH in bathrooms and 10,000 in bedrooms.

- Must be equipped with an oxygen-depletion sensor.
- Room containing the heater must have adequate combustion air.
- Home must have adequate ventilation: *See "Evaluating Home Ventilation Levels" on page 74.*
- Further guidance on unvented space heaters is found in WPN 08-4 and WPN 11-6.

8.3 Testing Gas Furnaces

The goal of a combustion analysis is to quickly analyze combustion and heat exchange. Within ten minutes of activating a furnace, you can know its most critical operating parameters. This information can save you from uncertainty along with a host of unnecessary maintenance procedures or code prescriptions.





Atmospheric, open combustion Gas Burners: Combustion air comes from indoors in open combustion appliances. These burners use the heat of the flame to pull combustion air into the burner. Dilution air, entering at the draft diverter, prevents overfire draft from becoming excessive.

Modern flue gas analyzers measure O_2, CO, and flue gas temperature. The better models also measure draft. Flue gas analyzers also calculate combustion efficiency or steady-state efficiency (SSE). Using a modern electronic flue gas analyzer, an experienced contractor can test a furnace and obtain its critical operating parameters quickly.

A common furnace-efficiency problem is low fuel input and high O_2, resulting in poor heat transfer. This condition can only be detected by combustion testing. Optimizing the steady-state efficiency (SSE) and fuel-air mixture can save 2–8% of the furnace's fuel consumption.

Flue gas temperature is another important indicator of furnace performance. A low flue gas temperature is usually an indicator of efficient performance. However, if the flue gas temperature is too low in older furnaces or 80+ furnaces, acidic condensation forms in the vent. This acidic condensate can rust metal vents and damage masonry chimneys.

70+ Furnace: Sample flue gases within the draft diverter inside each exhaust port.

80+ Furnace: Measure draft and sample flue gases in the vent connector above the furnace.

8.3.1 Furnace Efficiency Testing

Perform the following procedures to verify a furnace's correct operation.

- Perform a combustion test using a electronic flue gas analyzer. Recommended flue gas temperature depends on the type of furnace and is listed in the table titled, *"Combustion Standards for Gas Furnaces" on page 198*.
- Measure temperature rise (supply minus return temperatures). Temperature rise should be within the manufacturer's specifications. Estimate the airflow from the furnace's blower specifications and compare the furnace's rated output to output estimated by the table titled: *"Gas-Furnace Output from Temperature Rise and Airflow (1000s BTUH)" on page 196*
- If O_2 is high, or the estimated output from the table is low, increase gas pressure to 6% O_2 if possible as long as you don't create CO.

- Increase gas pressure if needed to increase temperature rise and flue gas temperature.

If you know the airflow through the furnace from measurements described in *"Evaluating Forced-Air System Airflow" on page 255*, you can use the table, *"Gas-Furnace Output from Temperature Rise and Airflow (1000s BTUH)" on page 196*, to check whether output is approximately what the manufacturer intended. Dividing this output by measured input from *"Inspecting Gas Combustion Systems" on page 201* gives you another check on the steady-state efficiency.

Troubleshooting Temperature Rise

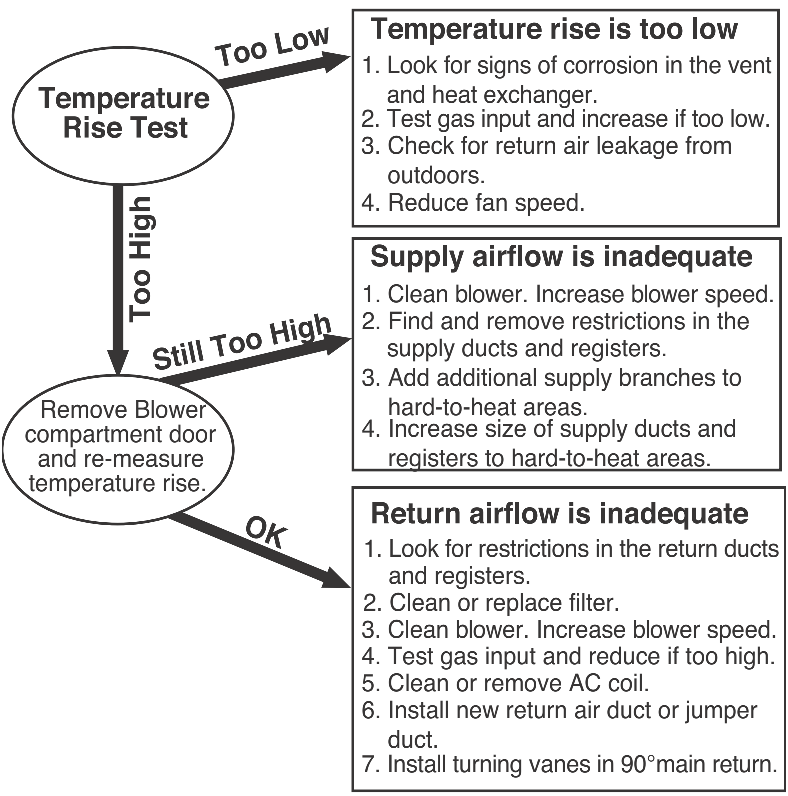


Table 8-1: Gas-Furnace Output from Temperature Rise and Airflow (1000s BTUH)

CFM	Temperature Rise (Supply F° – Return F°)					
	30	40	50	60	70	80
600	19.4	25.9	32.4	38.9	45.4	51.8
700	22.7	30.2	37.8	45.4	52.9	60.5
800	25.9	34.6	43.2	51.8	60.4	69.1
900	29.2	38.9	48.6	58.3	68.0	77.8
1000	32.4	43.2	54.0	64.8	75.6	86.4
1100	35.6	47.5	59.4	71.3	83.2	95.0
1200	38.9	51.8	64.8	77.8	90.7	103.7
1300	42.1	56.2	70.2	84.2	98.3	112.3
1400	45.4	60.5	75.6	90.7	105.8	121.0
1500	48.6	64.8	81.0	97.2	113.4	129.6

Table 8-2: Action Levels for open combustion Gas Appliances

CO Level		Draft and Spillage	Required Action
0 – 25 ppm	and	Passes	Proceed with work.
26 –100 ppm	and	Passes	Recommend that the CO problem be fixed.
26 –100 ppm	and	Fails at worst-case only	Recommend a service call for the appliance and/or repairs to the home to correct the problem.
100 –400 ppm	or	Fails under normal conditions	**Stop Work:** Work may not proceed until the system is serviced and the problem is corrected.
>400 ppm	and	Passes	**Stop Work:** Work may not proceed until the system is serviced and the problem is corrected.
>400 ppm	and	Fails under any conditions	**Emergency:** Shut off the fuel to the appliance and ask the homeowner to call for service immediately.
Courtesy: Building Performance Institute Inc.			

Table 8-3: Combustion Standards for Gas Furnaces

Performance Indicator	SSE 70+	SSE 80+	SSE 90+
Carbon monoxide (CO) (ppm)	<100 ppm	<100 ppm	<100 ppm
Stack temperature (°F)	350°–475°	325°–450°	<120°
Temperature rise (°F)	40–70°*	40–70°*	30–70°*
Oxygen (%O_2)	5–10%	4–9%	4–9%
Gas pressure Inches (IWC)	3.2–4.2 IWC*	3.2–4.2 IWC*	3.2–4.2 IWC*
Steady-state efficiency (SSE) (%)	72–78%	78–82%	92–97%
Draft (Pa)	-5 Pa	-5 Pa	+25–60 Pa
* pmi = per manufacturer's instructions			

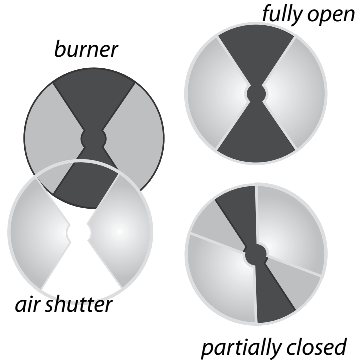
Table 8-4: Carbon Monoxide Causes and Solutions

Cause	Analysis & Solution
Flame smothered by combustion gases.	Chimney backdrafting from CAZ depressurization or chimney blockage.
Burner or pilot flame impinges.	Align burner or pilot burner. Reduce gas pressure if excessive.
Inadequate combustion air with too rich fuel-air mixture.	O_2 is <6%. Gas input is excessive or combustion air is lacking. Reduce gas or add combustion air.
Blower interferes with flame.	Inspect heat exchanger. Replace furnace or heat exchanger.
Primary air shutter closed.	Open primary air shutter.
Dirt and debris on burner.	Clean burners.
Excessive combustion air cooling flame.	O_2 is >11%. Increase gas pressure.

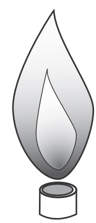
Table 8-5: Combustion Problems and Possible Solutions

Problem	Possible causes and solutions
Weak draft with CAZ depressurization	Supply duct leaks, clothes dryer, exhaust fans, other chimneys. Seal return leaks. Provide make-up air.
Weak draft with no CAZ depressurization	Chimney or vent connector is blocked, leaky, incorrectly sized, or has inadequate slope. Or else CAZ is too airtight.
Carbon monoxide	Mixture too rich or too lean. Adjust gas pressure. Check chimney and combustion air for code compliance.
Stack temperature or temperature rise too high or low	Adjust fan speed or gas pressure. Improve ducts to increase airflow.
Oxygen too high or low	Adjust gas pressure, but don't increase CO level.
CAZ = Combustion Appliance Zone *See "Essential Combustion Safety Tests" on page 208.*	

8.4 Critical Furnace-Testing Parameters



Primary Air Adjustment: Primary air shutters are usually fully open for natural gas combustion and partially closed for propane depending on flame characteristics. Too much primary air can cause noise and flame lift-off. Too little causes a lazy flame, searching for air. A good flame is hard and blue with an inner and outer mantle.



The following group of furnace-testing parameters are the most important ones because they tell you how efficient and safe the furnace currently is and how much you might be able to improve efficiency.

Carbon monoxide (CO) (ppm): Poisonous gas indicates incomplete combustion. Adjusting combustion to produce less than 100 ppm is almost always possible with gas-pressure adjustments, primary-air adjustments, or burner maintenance.

Oxygen (percent): Indicates the percent of excess air and whether fuel-air mixture is correct. Oxygen is directly related to furnace efficiency. Percent O_2 may also clarify the cause of CO as either too little or too much combustion air.

Flue gas temperature: The critical heat exchange measurement, flue gas temperature is directly related to furnace efficiency. Too high flue gas temperature wastes energy and too-low flue gas temperature leads to condensation and inadequate draft.

Airflow: The current furnace airflow and the likelihood of being able to increase it are very important to determine. During testing, airflow is artificially increased and the effect on flue gas temperature and temperature rise is observed. Measuring airflow also allows you to measure furnace output fairly accurately so you can compare it to output as listed on the furnace nameplate.

8.5 Inspecting Gas Combustion Systems

Gas burners should be inspected and maintained annually. These following specifications apply to gas furnaces, water heaters, and space heaters.

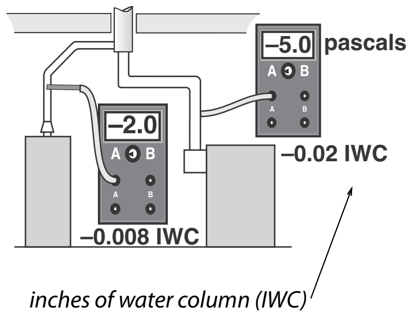
Perform the following inspection procedures and maintenance practices on all gas-fired furnaces, water heaters, and space heaters, as necessary. The goal of these measures is to reduce carbon monoxide (CO), stabilize flame, and verify the operation of safety controls.

- ✓ Look for soot, melted wire insulation, and rust in the burner and manifold inside and outside the burner compartment. These signs indicate flame roll-out, combustion gas spillage, CO, and incomplete combustion.
- ✓ Inspect the burners for dust, debris, misalignment, flame-impingement, and other flame-interference problems. Clean, vacuum, and adjust as needed.
- ✓ Inspect the heat exchanger for leaks.
- ✓ Furnaces should have dedicated circuits with fused disconnects, which must have a safety shutoff near the appliance. Verify that all 120-volt wiring connections are enclosed in covered electrical boxes.
- ✓ Determine that pilot is burning (if equipped) and that main burner ignition is satisfactory.
- ✓ For programmable thermostats, refer to manufacturer's instructions about how to control cycle length. These instructions may be printed inside the thermostat.

✓ Check venting system for proper diameter and pitch. See page 216.

✓ Check venting system for obstructions, blockages, or leaks.

✓ Observe flame characteristics if soot, CO, or other combustion problems are present. Flames should be blue and well shaped. If flames are white or yellow, this is further evidence of faulty combustion.



Measuring Draft: Measure chimney draft *downstream* of the draft diverter.

✓ If you measure CO, open a window while observing CO level on the meter to see if CO is reduced by increasing the available combustion air through the open window. See page 225.

Proceed with burner cleaning and adjustment in these cases.

- CO is greater than 100 ppm.
- Visual indicators of soot or flame roll-out exist.
- Burners are visibly dirty.
- Measured draft is inadequate. See page 208.
- The appliance has not been serviced for two years or more.

Gas-burner and gas-venting maintenance should include the following measures.

✓ Remove causes of CO and soot, such as over-firing, closed primary air intake, flame impingement, and lack of combustion air.

✓ Remove dirt, rust, and other debris that may be interfering with the burners. Clean the heat exchanger, if there are signs of soot around the burner compartment.

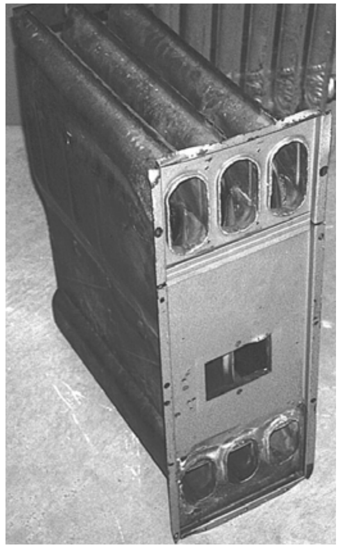
- ✓ Take action to improve draft, if inadequate because of improper venting, obstructed chimney, leaky chimney, or depressurization. *See page 213.*
- ✓ Seal leaks in vent connectors and chimneys.
- ✓ Adjust gas input if combustion testing indicates overfiring or underfiring.

8.5.1 Inspecting Furnace Heat Exchangers

Leaks in heat exchangers are a common problem, causing the flue gases to mix with house air. Ask clients about respiratory problems, flue-like symptoms, and smells in the house when the heat is on. Also, check around supply registers for signs of soot, especially with oil heating. All furnace heat exchangers should be inspected as part of weatherization. Consider using one or more of the following 7 general options for evaluating heat exchangers.

1. Look for rust at exhaust ports and vent connector.
2. Look for flame impingement on the heat exchanger during firing.
3. Observe flame movement, change in chimney draft, or change in CO reading as blower is turned on and off.
4. Look for flame-damaged areas near the burner flame.
5. Measure the flue-gas oxygen concentration before the blower starts and just after it has started. There should be no more than a 1% change in the oxygen concentration.

6. Examine the heat exchanger, shining a bright light on one side and looking for light traces on the other using a mirror to peer into tight locations.
7. Employ chemical detection techniques, following manufacturer's instructions.



Furnace heat exchangers: Although no heat exchanger is completely airtight, it should not leak enough to display the warning signs described here.

8.6 Wood Stoves

Wood heating is a popular and effective auxiliary heating source for homes. However, wood stoves and fireplaces can cause indoor air pollution and fire hazards. It's important to inspect wood stoves to evaluate potential hazards.

8.6.1 Wood Stove Clearances

Stoves that are listed by a testing agency like Underwriters Laboratory have installation instructions stating their clearance from combustibles. Unlisted stoves must adhere to clearances specified in NFPA 211.

8.6.2 Stove Clearances

Look for metal tags on the wood stove that list minimum clearances. Unlisted stoves must be at least 36 inches away from combustibles. However, listed wood stoves may be installed to as little as 6 inches away from combustibles, if they incorporate heat shields and combustion design that directs heat away from the back and sides. Ventilated or insulated wall protectors may also decrease unlisted clearance from one-third to two thirds, according to NFPA 211. Always follow the stove manufacturer's or heat-shield manufacturer's installation instructions.

Floor Construction and Clearances

Wood stoves must rest of a floor of noncombustible construction. An example of a noncombustible floor is one composed of only masonry material sitting on dirt. This floor must extend no less than 18 inches beyond the stove in all directions. Approved floor protectors or the stove-bottom heat shields of listed stoves can allow the stove to rest on a floor containing combustible materials. The floor would need a minimum of one-quarter inch of grouted tile or an approved floor protector extending 18 inches away from the stove in all directions.

Vent-Connector and Chimney Clearance

Interior chimneys require a 2-inch clearance from combustibles and exterior chimneys require a 1-inch clearance from combustibles.

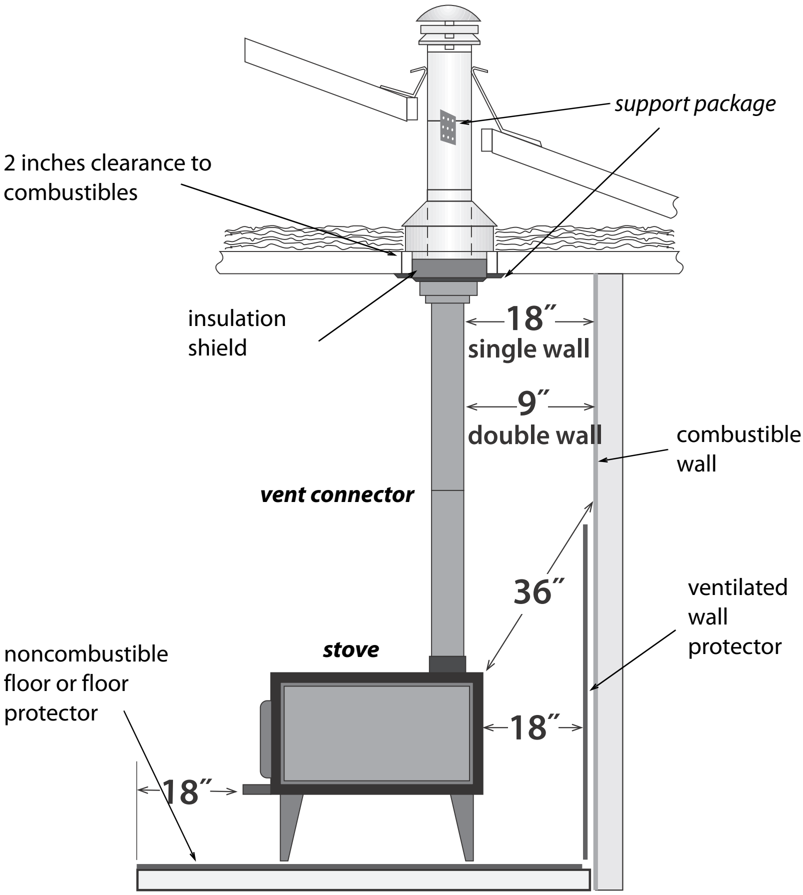
Single wall vent connectors must be at least 18 inches from combustibles. Wall protectors may reduce this clearance up to two-thirds. Type-L double wall vent pipe requires only a 9-inch clearance from combustibles.

See also *"Chimneys" on page 219* and *"Vent Connectors" on page 216*.

8.6.3 Wood Stove Inspection

All components of wood stove venting systems should be approved for use with wood stoves. Chimney sections penetrating floor, ceiling, or roof should have approved thimbles, support packages, and ventilated shields to protect combustible materials from high temperatures. The energy auditor should perform or specify the following inspection tasks.

- Inspect stove, vent connector, and chimney for correct clearances from combustible materials as listed in NFPA 211.
- If the home is tight (<0.35 air changes per hour), the wood stove should be equipped with outdoor combustion air.
- Galvanized steel pipe must not be used to vent wood stoves.
- Inspect vent connector and chimney for leaks. Leaks should be sealed with a high temperature sealant designed for sealing wood stove vents.
- Inspect chimney and vent connector for creosote build-up, and suggest chimney cleaning if creosote build-up exists.
- Inspect the house for soot on seldom-cleaned horizontal surfaces. If soot is present, inspect the wood stove door gasket. Seal stove air leaks or chimney air leaks with stove cement. Improve draft by extending the chimney to reduce indoor smoke emissions.
- Inspect stack damper and/or combustion air intake.
- Check catalytic combustor for repair or replacement if the wood stove has one.
- Assure that heat exchange surfaces and flue passages within the wood stove are free of accumulations of soot or debris.
- Wood stoves installed in mobile or manufactured homes must be approved for use in those homes.



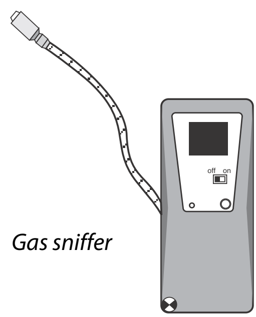
Wood Stove Installation: Wood stove venting and clearances are vitally important to wood-burning safety. Read manufacturer's instructions for the stove and its venting components.

8.7 Essential Combustion Safety Tests

The Building Performance Institute (BPI) requires that essential combustion safety tests be performed as part of all energy conservation jobs. BPI requires gas leak-testing and CO testing for all appliances. For naturally drafting appliances, a worst-case venting test and zone isolation test are also necessary.

8.7.1 Leak-Testing Gas Piping

Natural gas and propane piping systems may leak at their joints and valves. Find gas leaks with an electronic combustible-gas detector, often called a gas sniffer. A gas sniffer will find significant gas leaks if used carefully. Remember that natural gas rises from a leak and propane falls, so position the sensor accordingly.



Gas sniffer

- Sniff all valves and joints with the gas sniffer.
- Accurately locate leaks using a noncorrosive bubbling liquid, designed for finding gas leaks.
- All gas leaks must be repaired.
- Replace kinked or corroded flexible gas connectors.
- Replace flexible gas lines manufactured before 1973. The date is stamped on a date ring attached to the flexible gas line.

8.7.2 Carbon Monoxide (CO) Testing

CO testing is essential for evaluating combustion and venting. Measure CO in the vent of every combustion appliance you inspect and service. Measure CO in ambient air in both the home and combustion appliance zone (CAZ) during your inspection and testing of combustion appliances.

Vent Testing for CO

Testing for CO in the appliance vent is a part of combustion that takes place under worst-case conditions. If CO is present in undiluted combustion byproducts more than 100 parts per million (ppm), the appliance fails the CO test.

Ambient Air Monitoring for CO

BPI standards require contractors to monitor CO during testing to ensure that air in the CAZ doesn't exceed 35 parts per million. If ambient CO levels in the combustion zone exceed 35 parts per million (ppm), stop testing for the your own safety. Ventilate the CAZ thoroughly before resuming combustion testing. Investigate indoor CO levels of 9 ppm or greater to find their cause. This is the ASHRAE 24 hour exposure limit.

Table 8-6: Testing Requirements for Combustion Appliances and Venting Systems

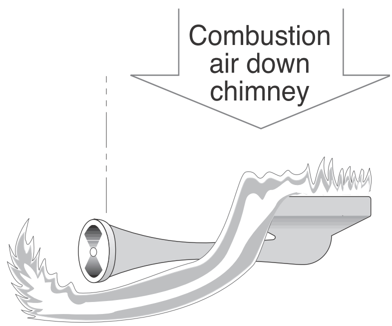
Appliance/Venting System	Required Testing
All direct vent or power vent combustion appliances	Gas leak test CO test at flue gas exhaust outdoors Confirm venting system connected
Combustion appliances (with naturally drafting chimneys) in a mechanical room or attached garage supplied with outdoor combustion air and sealed from the home	Gas leak test CO test Confirm that CAZ is effectively air sealed from house and has combustion air from outdoors
Naturally drafting chimney and appliance located within home	Gas leak test CO test Venting inspection Worst-case draft and depressurization testing

8.7.3 Worst-Case Testing for Atmospheric Venting Systems

Depressurization is the leading cause of backdrafting and flame roll-out in furnaces and water heaters that vent into naturally drafting chimneys. Perform the worst-case testing procedures documented here.

Worst-case vent testing uses the home's exhaust fans, air handler, and chimneys to create worst-case depressurization in the combustion-appliance zone (CAZ). The CAZ is an area containing one or more combustion appliances. During this worst-case testing, you can test for spillage, measure the indoor-outdoor pressure difference, and measure chimney draft.

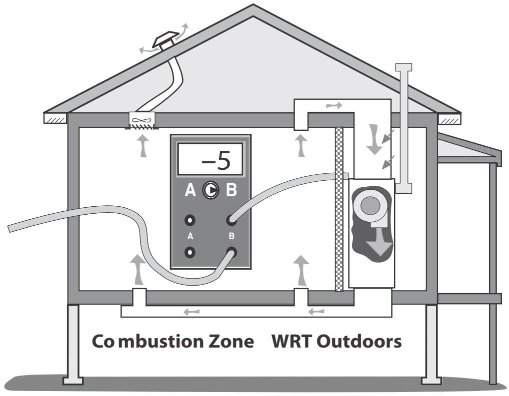
Worst-case conditions do occur, and venting systems must exhaust combustion by-products even under these extreme conditions. Worst-case vent testing exposes whether or not the venting system exhausts the combustion gases when the combustion-zone pressure is as negative as you can make it. A sensitive digital manometer is the best tool for accurate and reliable readings of both combustion-zone depressurization and chimney draft.



Flame Roll-Out: Flame roll-out, a serious fire hazard, can occur when the chimney is blocked, the combustion zone is depressurized, or during very cold weather.

Take all necessary steps to reduce spillage and strengthen draft as necessary based on testing.

A reading more negative than -5 pascals indicates a significant possibility of backdrafting.



Worst-Case Depressurization: Worst-case testing is used to identify problems that weaken draft and restrict combustion air. The testing described here is intended to isolate the negative-pressure source.

8.7.4 Worst-Case Depressurization, Spillage, and CO

Set all combustion appliances to the pilot setting or turn them off at the service disconnect.Then make sure all exterior doors, windows, and fireplace damper(s) are closed, and measure the base pressure.

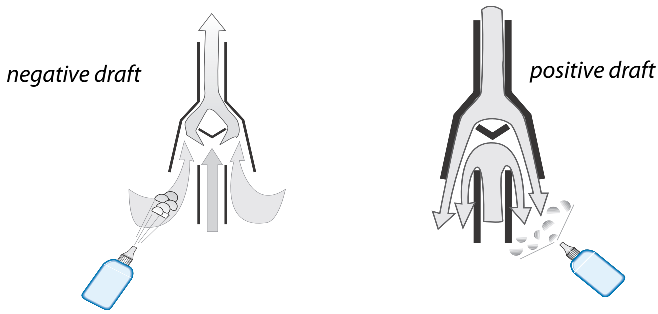
Measure and record the base pressure of the combustion appliance zone (CAZ) with reference to outdoors. If the digital manometer has a baseline function, use this function to cancel out the baseline pressure now.

Then establish worst-case conditions and measure the maximum worst-case depressurization.

1. Turn on the dryer and all exhaust fans.
2. Close the interior doors, which make the CAZ pressure more negative. Experiment by opening and closing interior doors while the air handler is operating.
3. Turn on the air handler, if present, using the “fan on” switch. Leave on if the pressure in the CAZ becomes

more negative. Do not fire the burner of the combustion appliance yet.

4. Measure the worst-case pressure and record it. Compare this number to the table entitled, *"Maximum CAZ or Mechanical Room Depressurization for Various Appliances" on page 213* for the tested appliance.
5. Next, the appliance with the smallest BTU capacity first and then the next largest and so on. Test for spillage and CO as required below.
6. Test for spillage at the draft diverter with a smoke generator, a lit match, or a mirror. Note whether combustion by-products spill and how long after ignition that the spillage stops.
7. Test CO in the undiluted flue gases at 5 minutes.
8. If spillage in one or more appliances continues under worst-case for 1 minute or more, test the appliance again under natural conditions.
9. Test for CO in undiluted flue gases of combustion appliances. If CO in undiluted flue gases is more than 100 ppm as measured or 200 ppm air-free measurement, specify service to reduce CO to below these maximum levels (unless your CO measurement is within manufacturers specifications).



Negative Versus Positive Draft: With positive draft air flows down the chimney and out the draft diverter. A smoke bottle helps distinguish between positive and negative draft in atmospheric chimneys.

Table 8-7: Maximum CAZ or Mechanical Room Depressurization for Various Appliances

Appliance	Maximum Depressurization
Sealed-combustion appliance; appliances with wall or rooftop power venter	50 pa (0.20 IWC)
Power-vented furnace or boiler; pellet stove with draft fan and sealed vent	15 pa (0.06 IWC)
Atmospherically vented gas systems	5 pa (0.02 IWC)
Oil power burner and fan-assisted (induced-draft) gas*	
Closed controlled combustion	
Decorative wood-burning appliances	
Atmospherically vented water heater	2 pa (0.008 IWC)

*Individual fan-assisted (induced-draft) appliances with no vent hood attached to intact b-vent appliances with flame retention head power burners are likely to vent safely at greater than 5 pascals depressurization but not enough test data is available to set a higher limit at this time. Since the appliances are possibly connected to an unsealed chimney and most spillage is through joints and the barometric damper these systems are included in the 5pa limit.

8.7.5 Improving Inadequate Draft

If measured draft is below minimum draft pressures, investigate the reason for the weak draft. Open a window, exterior door, or interior door to observe whether the addition of combustion air improves draft. If this added air strengthens draft, the problem usually is depressurization. If opening a window doesn't improve draft, inspect the chimney. The chimney could be blocked or excessively leaky.

Chimney Improvements to Solve Draft Problems

Suggest the following chimney improvements to solve draft problems uncovered during the previous testing.

- Remove chimney obstructions.
- Repair disconnections or leaks at joints and where the vent connector joins a masonry chimney.
- Measure the size of the vent connector and chimney and compare to vent-sizing information listed in Section 504 of the *International Fuel Gas Code*. A vent connector or chimney liner that is either too large or too small can result in poor draft.
- If wind is causing erratic draft, consider installing a wind-dampening chimney cap.
- If the masonry chimney is deteriorated, consider installing a new chimney liner.
- Increase the pitch of horizontal sections of vent.

Duct Improvements to Solve Draft Problems

Suggest the following duct improvements to solve draft problems, uncovered during the previous testing.

- Seal all return duct leaks near furnace.
- Isolate the CAZ from return registers by air sealing.
- Reducing depressurization from exhaust appliances

Consider suggesting the following remedies to depressurization caused by the home's exhaust appliances.

- Isolate furnace from exhaust fans and clothes dryers by air sealing between the CAZ and zones containing these exhaust devices.
- Provide make-up air for dryers and exhaust fans and/or provide combustion air inlet(s) to combustion zone. *See page 225.*

Table 8-8: Draft Problems and Solutions

Problem	Possible Solutions
Adequate draft never established	Remove chimney blockage, seal chimney air leaks, or provide additional combustion air as necessary.
Blower activation weakens draft	Seal leaks in the furnace and in nearby return ducts. Isolate the furnace from nearby return registers.
Exhaust fans weaken draft	Provide make-up or combustion air if opening a door or window to outdoors strengthens draft during testing.

8.7.6 Zone Isolation Testing for Atmospherically Vented Appliances

An isolated CAZ improves the safety of atmospherically vented appliances. The CAZ is isolated if it obtains combustion air only from outdoors. An isolated CAZ doesn't require worst-case depressurization and spillage testing. However the zone must be visually inspected for connections with the home's main zone and tested for isolation.

1. Look for connections between the isolated CAZ and the home. Examples include joist spaces, transfer grills, leaky doors, and holes for ducts or pipes.
2. Measure a base pressure from the CAZ to outdoors.
3. Perform 50-pascal blower door depressurization test. The CAZ-to-outdoors pressure should not change more than 5 pascals during the blower door test. *See "Bedroom test" on page 85.*
4. If the CAZ-to-outdoors pressure changed more than 5 pascals, perform air sealing to completely isolate the zone and retest as described in steps 2 and 3.

5. If you can't seal the CAZ adequately to isolate the zone, perform a worst-case depressurization and spillage test as described in *"Worst-Case Depressurization, Spillage, and CO" on page 211*.

8.8 Inspecting Venting Systems

Combustion gases are vented through vertical chimneys or other types of approved horizontal or vertical vent piping. Identifying the type of existing venting material, verifying the correct size of vent piping, and making sure the venting conforms to the applicable codes are important tasks in inspecting and repairing venting systems. Too large a vent often leads to condensation and corrosion. Too small a vent can result in spillage. The wrong vent materials can corrode or deteriorate from heat.

NFPA Codes

The National Fire Protection Association (NFPA) publishes authoritative information sources on material-choice, sizing, and clearances for chimneys and vent connectors, as well as for combustion air. The information in this venting section is based on the following NFPA documents.

- NFPA 54: The *National Fuel Gas Code 2006*
- NFPA 211: *Standard for Chimneys, Fireplaces, Vents, and Solid-Fuel-Burning Appliance*s 2006

8.8.1 Vent Connectors

A vent connector connects the appliance's venting outlet with the chimney. Approved vent connectors for gas-fired units are made from the following materials.

- Type-B vent, consisting of a galvanized steel outer pipe and aluminum inner pipe
- Type-L vent connector with a stainless-steel inner pipe and either galvanized or black-steel outer pipe.

- Galvanized steel pipe (≥ 0.019 inch thick or 20 gauge) for vent connectors 5 inches in diameter or less.
- Galvanized steel pipe (≥ 0.023 inch thick or 22 gauge) for vent connectors 6-to-10 inches in diameter.

Double wall vent connectors are the best option, especially for appliances with some nonvertical vent piping. A double wall vent connector helps maintain flue gas temperature and prevent condensation. Gas appliances with draft hoods, installed in attics or crawl spaces must use a Type-B vent connector. Type-L vent pipe is commonly used for vent connectors for solid fuels but can also be used for gas.

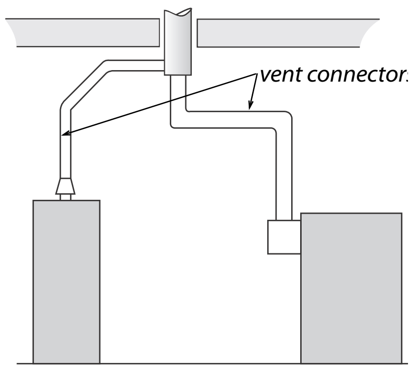
Observe the following general specifications, concerning vent connectors.

- Vent connectors must be as large as the vent collar on the appliances they vent.
- Single wall vent-pipe sections should be fastened together with 3 screws or rivets.
- Vent connectors should be sealed tightly where they enter masonry chimneys.
- Vent connectors should be free of rust, corrosion, and holes.
- The chimney combining two vent connectors should have a cross-sectional area equal to the area of the larger vent connector plus half the area of the smaller vent connector. This common vent should be no larger than 7 times the area of the smallest vent. For specific vent sizes, see the NFPA codes listed on *page 216.*

Table 8-9: Areas of Round Vents

Vent diameter	4"	5"	6"	7"	8"
Vent area (square inches)	12.6	19.6	28.3	38.5	50.2

- The horizontal length of vent connectors shouldn't be more than 75% of the chimney's vertical height or have more than 18 inches horizontal run per inch of vent diameter.



Two vent connectors joining chimney: The water heater's vent connector enters the chimney above the furnace because the water heater has a smaller input.

- Vent connectors must have upward slope to their connection with the chimney. NFPA 54 requires a slope of at least $^1/_4$ inch of rise per foot of horizontal run to ensure that combustion gases rise through the vent and to prevent condensation from pooling and rusting the vent. *See "Clearances to Combustibles for Common Chimneys" on page 220.*

Table 8-10: Connector Diameter vs. Maximum Horizontal Length

Diameter (in)	3"	4"	5"	6"	7"	8"	9"	10"	12"	14"
Length (ft)	4.5'	6'	7.5'	9'	10.5'	12'	13.5'	15'	18'	21'

From *International Fuel Gas Code 2000*

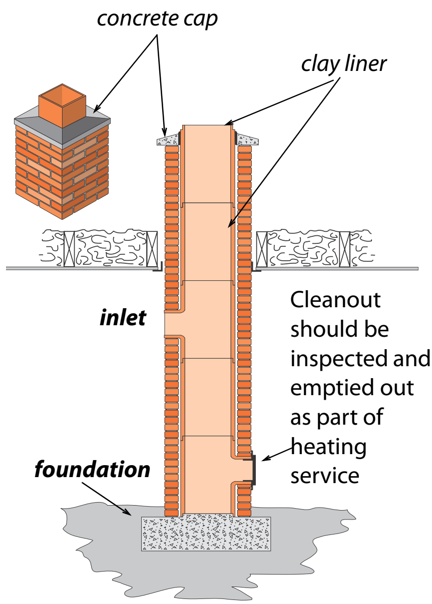
- When two vent connectors connect to a single chimney, the vent connector servicing the smaller appliance should enter the chimney above the vent for the larger appliance.
- Clearances for common vent connectors are listed in the following table.

Table 8-11: Clearances to Combustibles for Vent Connectors

Vent Connector Type	Clearance
Single wall galvanized steel vent pipe	6" (gas) 18" (oil)
Type-B double wall vent pipe (gas)	1" (gas)
Type L double wall vent pipe (stainless steel inner liner, stove pipe or galvanized outer liner)	9", or 1 vent diameter, or as listed

8.9 Chimneys

There are two common types of vertical chimneys for venting combustion fuels that satisfy NFPA and ICC codes. First there are masonry chimneys lined with fire-clay tile, and second there are manufactured metal chimneys, including all-fuel metal chimneys and Type-B vent chimneys for gas appliances.



Masonry chimneys: Remain a very common vent for all fuels.

8.9.1 Masonry Chimneys

Observe the following general specifications for building, inspecting, and repairing masonry chimneys.

- Masonry chimneys should be supported by their own masonry foundation.
- Existing masonry chimneys should be lined with a fireclay flue liner. There should be a $^{1}/_{2}$-inch to 1-inch air gap

between the clay liner and the chimney's masonry to insulate the liner. The liner shouldn't be bonded structurally to the outer masonry because it needs to expand and contract independently of the chimney's masonry structure. The clay liner can be sealed to the chimney cap with a flexible high temperature sealant.

- Masonry chimneys should have a cleanout 12 inches or more below the lowest inlet. Mortar and brick dust should be cleaned out of the bottom of the chimney through the clean-out door, so that this debris won't eventually interfere with venting.
- The chimney's penetrations through floors and ceilings should be sealed with metal and high temperature sealant as a firestop and air barrier.
- Deteriorated or unlined masonry chimneys should be rebuilt as specified above or relined as part of a heating-system replacement or a venting-safety upgrade. As an alternative, the vertical chimney may be replaced by a sidewall vent, equipped with a power venter mounted on the exterior wall. In this case, the old chimney should be sealed up and taken out of service.
- A new metal chimney should be installed instead of repairing the existing masonry chimney.

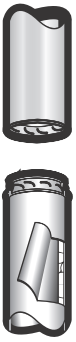
Table 8-12: Clearances to Combustibles for Common Chimneys

Chimney Type	Clearance
Interior chimney masonry w/ fireclay liner	2"
Exterior masonry chimney w/ fireclay liner	1"
All-fuel metal vent: insulated double wall or triple-wall pipe	2"
Type B double wall vent (gas only)	1"
Manufactured chimneys and vents list their clearance	

8.9.2 Manufactured Chimneys

Manufactured metal chimneys have engineered parts that fit together in a prescribed way. Metal chimneys contain manufactured components from the vent connector to the termination fitting on the roof. Manufactured-chimney parts include the following: metal pipe, weight-supporting hardware, insulation shields, roof jacks, and chimney caps. One manufacturer's chimney may not be compatible with another's connecting fittings.

All-fuel chimneys (also called Class A chimneys) are used primarily for solid fuels like wood and coal. All-fuel metal chimneys come in two types: insulated double wall metal pipe and triple-wall metal pipe. Install them strictly observing the manufacturer's specifications.

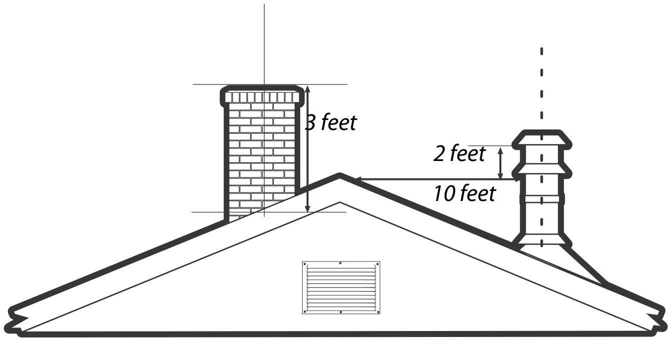


All-fuel metal chimney: These chimney systems include transition fittings, support brackets, roof jacks, and chimney caps. The pipe is double wall insulated or triple wall.

Type-B vent pipe is permitted as a chimney for gas appliances. Type BW pipe is manufactured for gas space heaters in an oval shape to fit inside. wall cavities.

8.9.3 Chimney Terminations

Masonry chimneys and all-fuel metal chimneys should terminate at least three feet above the roof penetration and two feet above any obstacle within ten feet of the chimney outlet.



Chimney terminations: Should have vent caps and be given adequate clearance height from nearby building parts. These requirements are for both masonry chimneys and manufactured all-fuel chimneys.

B-vent chimneys can terminate as close as one foot above flat roofs and pitched roofs up to a $^6/_{12}$ roof pitch. As the pitch rises, the minimum required termination height, as measured from the high part of the roof slope, rises as shown in the table.

Table 8-13: Roof Slope and B-Vent Chimney Height (ft)

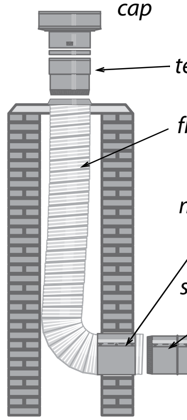
flat-6/12	6/12-7/12	7/12-8/12	8/12-9/12	9/12-10/12	10/12-11/12	11/12-12/12	12/12-14/12	14/12-16/12	16/12-18/12
1'	1' 3"	1' 6"	2'	2' 6"	3' 3"	4'	5′	6'	7'

From *International Fuel Gas Code 2000*

8.9.4 Metal Liners for Masonry Chimneys

Unlined masonry chimneys or chimneys with deteriorated liners should be relined as part of heating system replacement. Use either Type-B vent, a flexible or rigid stainless-steel liner, or a flexible aluminum liner.

Flexible liners require careful installation to avoid a low spot at the bottom, where the liner turns a right angle to pass through the wall of the chimney. Follow the manufacturer's instructions, which usually prescribe stretching the liner and fastening it securely at both ends, to prevent it from sagging and thereby creating such a low spot.



Flexible metal chimney liners: The most important installation issues are sizing the liner correctly along with fastening and supporting the ends to prevent sagging.

Flexible liners are easily damaged by falling masonry debris inside a deteriorating chimney. Use B-vent instead of a flexible liner when the chimney is significantly deteriorated.

To minimize condensation, flexible liners should be insulated — especially when installed in exterior chimneys. Consider insulating flexible metal chimney liners with vermiculite or a fiberglass-insulation jackets, if the manufacturer's instructions allow.

Sizing flexible chimney liners correctly is very important. Oversizing is common and can lead to condensation and corrosion. The manufacturers of the liners include vent-sizing tables in their instructions. Liners should bear the label of a testing lab like Underwriters Laboratories (UL).

8.10 Special Venting Considerations for Gas

The American Gas Association (AGA) has devised a classification system for venting systems serving natural gas and propane appliances. This classification system assigns Roman numerals to four categories of venting based on whether there is positive or negative pressure in the vent and whether condensation is likely to occur in the vent.

	Negative-pressure Venting	Positive-pressure
Non-condensing	I Combustion Efficiency **83% or less** Use standard venting: masonry or Type B vent	III Combustion Efficiency **83% or less** Use only pressurizable vent as specified by manufacturer
Condensing	II Combustion Efficiency **over 83%** Use only special condensing-service vent as specified by manufacturer	IV Combustion Efficiency **over 83%** Use only pressurizable condensing-service vent as specified by manufacturer

American Gas Association Vent Categories

AGA venting categories: The AGA classifies venting by whether there is positive or negative pressure in the vent and whether condensation is likely.

A majority of gas appliances found in homes and multifamily buildings are Category I, which have negative pressure in vertical chimneys with no condensation expected in the vent connector or chimney. Condensing furnaces are usually Category IV with positive pressure in their vent and condensation occurring in both the appliance and vent. Category III vents are rare but some fan-assisted appliances are vented with airtight noncondensing vents.

8.10.1 Venting Fan-Assisted Furnaces

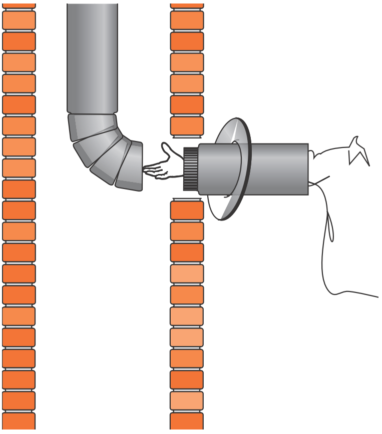
Newer gas-fired fan-assisted central furnaces control flue gas flow and excess air better than atmospheric furnaces, resulting in their higher efficiency. These are non-condensing Category I furnaces in the 80%-plus Annual Fuel Utilization Efficiency (AFUE) range. Because these units eliminate dilution air and may have slightly cooler flue gases, existing chimneys should be carefully inspected to ensure that the chimneys are prepared for more condensation than they have experienced in the past. The chimney should be relined when any of the following conditions are present.

- When the existing masonry chimney is unlined.
- When the old clay or metal chimney liner is deteriorated.
- When the new furnace has a smaller input (BTUH) than the old one, the liner should be sized to the new furnace and the existing water heater.

Materials for 80+ Furnaces

For gas-fired 80+ AFUE furnaces, a chimney liner should consist of one of these materials.

- Type-B vent
- A rigid or flexible stainless steel liner (preferably insulated)
- A poured masonry liner
- An insulated flexible aluminum liner



B-vent chimney liner: Double wall Type-B vent is the most commonly available chimney liner and is recommended over flexible liners. Rigid stainless-steel single wall liners are also a permanent solution to deteriorated chimneys.

Because of the considerable expense that chimney relining can entail, sidewall venting with a power venter or heating-system replacement with a 90+ condensing heater should be considered when an existing chimney is inadequate for new Category I appliances.

8.11 COMBUSTION AIR

A combustion appliance zone (CAZ) is classified as either an un-confined space or confined space. An un-confined space is a CAZ connected to enough building air leakage to provide combustion air. A confined space is a CAZ with sheeted walls and ceiling and a closed door that form an air barrier between the appliance and other indoor spaces. For confined spaces, the IFGC prescribes additional combustion air from outside the CAZ. Combustion air is supplied to the combustion appliance in four ways.

1. To an un-confined space through leaks in the building.
2. To a confined space through an intentional opening or openings between the CAZ and other indoor areas where air leaks replenish combustion air.
3. To a confined space through an intentional opening or openings between the CAZ and outdoors or ventilated intermediate zones like attics and crawl spaces.
4. Directly from the outdoors to the appliance. Appliances with direct combustion air supply are called sealed-combustion or direct vent appliances.

Table 8-14: Characteristics of Gas Furnaces

Annual Fuel Utilization Efficiency (AFUE)	Operating characteristics
70+	Category I, draft diverter, no draft fan, standing pilot, noncondensing, indoor combustion and dilution air.
80+	Category I, no draft diverter, draft fan, electronic ignition, indoor combustion air, no dilution air.
90+	Category IV, no draft diverter, draft fan, low-temperature plastic venting, positive draft, electronic ignition, condensing heat exchanger, outdoor combustion air is strongly recommended.

8.11.1 Un-Confined-Space Combustion Air

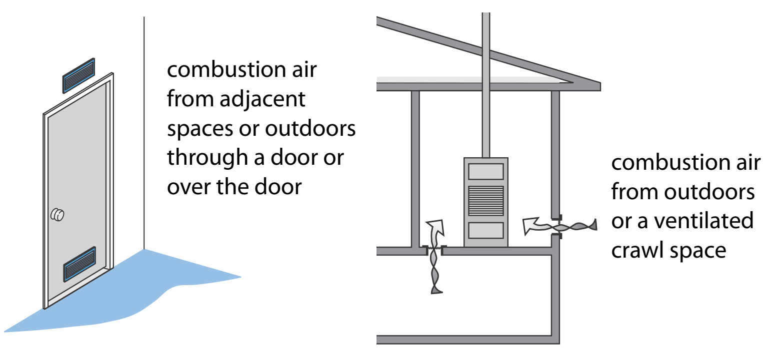
Combustion appliances located in most basements, attics, and crawl spaces get adequate combustion air from leaks in the building shell. Even when a combustion appliance is located within the home's living space, it gets adequate combustion air from air leaks, unless the house is airtight or the combustion zone is depressurized.

8.11.2 Confined-Space Combustion Air

A confined space is defined by the codes as a room containing one or more combustion appliances that has less than 50 cubic feet of volume for every 1000 BTUs per hour of appliance input.

However, if a small mechanical room is connected to adjacent spaces through large air passages like floor-joist spaces, the CAZ may not need additional combustion air despite sheeted walls and a door separating it from other indoor spaces. The extent of the connection between the CAZ and other spaces can be confirmed by worst-case draft testing or blower door pressure testing.

When the home is unusually airtight, the CAZ may be unable to provide adequate combustion air, even when the combustion zone is larger than the minimum confined-space room volume, defined above.



Passive Combustion Air Options: Combustion air can be supplied from adjacent indoor spaces or from outdoors. Beware of passive combustion air vents into the attic that could depressurize the combustion zone or allow moist indoor air to travel into the attic.

Combustion Air from Outdoors

In confined spaces or airtight homes where outdoor combustion air is needed, prefer a single vent opening installed as low in the CAZ as practical. A combustion air vent into an attic may depressurize the combustion zone or dump warm moist air into the attic. Instead, connect the combustion zone to a ventilated crawl space or directly to outdoors through a single low vent if possible.

Choose an outdoor location that is sheltered, where the wall containing the vent isn't parallel to prevailing winds. Wind blowing parallel to an exterior wall or at a right angle to the vent opening tends to de-pressurize both the opening and the CAZ connected to it.

Table 8-15: Combustion Air Openings: Location and Size

Location	Dimensions
Two direct openings to adjacent indoor space	Minimum area each: 100 in^2 1 in^2 per 1000 BTUH each Combined room volumes must be ≥ 50 ft^3/1000 BTUH
Two direct openings or vertical ducts to outdoors	Each vent should have 1 in^2 for each 4000 Btuh
Two horizontal ducts to outdoors	Each vent should have 1 in^2 for each 2000 BTUH
Single direct or ducted vent to outdoors	Single vent should have 1 in^2 for each 3000 BTUH

From the *National Fuel Gas Code (NFPA 54)*

Net free area is smaller than actual vent area and takes the blocking effect of louvers into account. Metal grilles and louvers provide 60% to 75% of their area as net free area while wood louvers provide only 20% to 25%. Combustion air vents should be no less than 3 inches in their smallest dimension.

Example Combustion Air Calculation

Here is an example of sizing combustion air to another indoor area. The furnace and water heater are located in a confined space. The furnace has an input rating of 100,000 BTUH. The water heater has an input rating of 40,000 BTUH. Therefore, there should be 280 in^2 of net free area of vent between the mechanical room and other rooms in the home.

([100,000 + 40,000] ÷ 1,000 = 140 x 2 in^2 = 280 in^2)

Each vent should therefore have a minimum of 140 in^2.

8.12 Ducted Air Distribution

The annual system efficiency of forced-air heating and air-conditioning systems is affected by the following issues.

- Duct leakage
- System airflow
- Blower operation
- Balance between supply and return air
- Duct insulation levels

The forced-air system usually offers more opportunity for energy savings and comfort improvement than improving combustion or refrigeration equipment.

The sequence of testing and evaluation has a logic. First, deal with the airflow problems because contractors might have to change the duct system substantially. After airflow modifications, test the ducts for leakage and evaluate whether they are located within the thermal boundary or not. Decide whether duct sealing is important and if so, find and seal the leaks. Finally, if supply ducts are outside the thermal boundary, insulate them. The following list summarizes this logical sequence.

1. Evaluate and/or measure duct air leakage.
2. Find duct leaks and seal them.
3. Consider insulating supply ducts.

Measuring duct leakage and airflow are the best ways of evaluating these two critical performance variables. The troubleshooting techniques are helpful in isolating the precise problem, but not in quantifying the problem. The effectiveness of the improvements can again be evaluated by airflow and duct-leakage measurement.

8.12.1 Solving Airflow Problems

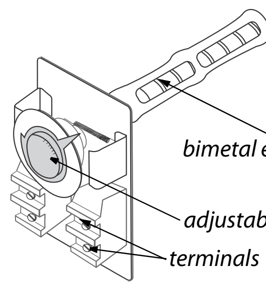
You probably don't need sophisticated test instruments to discover dirty blowers and coils or disconnected branch ducts. Finding these problems before measuring duct airflow speeds up the process of measurement, troubleshooting, and duct sealing. The following steps precede airflow measurements.

1. Ask the customer about comfort problems and temperature differences in various parts of the home.
2. Based on the customers comments, look for disconnected, restricted ducts, and other obvious problems.
3. Inspect the filter(s), blower, and indoor coil for dirt. Clean them if necessary. If the indoor coil isn't easily visible, a dirty blower is a fair indicator that the coil may also be dirty.
4. Inspect for dirty or damaged supply and return grilles that restrict airflow. Clean and repair them.
5. Look for closed registers or balancing dampers that could be restricting airflow to rooms.
6. Notice moisture problems like mold and mildew. Moisture sources, like a wet crawl space, can overpower air conditioners by introducing more moisture into the air than the air conditioner can remove.

8.12.2 Evaluating Furnace Performance

The effectiveness of a furnace depends on its temperature rise, fan-control temperatures, and flue gas temperature. For efficiency, you want a low temperature rise. However, you must maintain a minimum flue gas temperature to prevent corrosion in the venting of 70+ and 80+ AFUE furnaces. Apply the following furnace-operation standards to maximize the heating system's seasonal efficiency and safety.

- Perform a combustion analysis as described in *“Testing Gas Furnaces” on page 192*.
- Check temperature rise after 5 minutes of operation. Refer to manufacturer’s nameplate for acceptable temperature rise (supply temperature minus return temperature). The temperature rise should be between 40°F and 70°F with the lower end of this scale being preferable for energy efficiency.
- The fan-off temperature should be between 95° and 105° F, with the lower end of the scale being preferable for maximum efficiency.
- The fan-on temperature should be 120-140° F. The lower the better.
- On time-activated fan controls, verify that the fan is switched on within two minutes of burner ignition and is switched off within 2.5 minutes of the end of the combustion cycle.
- The high limit controller should shut the burner off before the furnace temperature reaches 200°F.



Fan/limit control: Turns the furnace blower on and off, according to temperature. Also turns the burner off if the heat exchanger gets too hot.

- Check blower compartment cover inter-lock switch to ensure it functions and will stop the blower from functioning when the blower compartment cover is not properly installed.
- All forced-air heating systems must deliver supply air and collect return air only within the intentionally heated portion of the house. Taking return air from an un-heated area of the house such as an unoccupied basement is not acceptable.

- There should be a strong noticeable flow of air from all supply registers.

Table 8-16: Furnace Operating Parameters

20°–45°	45°–70°	70°–95°
Inadequate temperature rise: condensation and corrosion possible.	Temperature rise OK for both efficiency and avoidance of condensation.	Temperature else excessive: Check fan speed, heat exchanger and ducts.

Temperature Rise = Supply Temperature – Return Temperature

85°–100°	100°–115°	115°–130°
Excellent fan-off temperature if comfort is acceptable.	Borderline acceptable: Consider replacing fan control.	Unacceptable range: Significant savings possible by adjusting or replacing fan control.

Fan-off Temperature

100°–120°	120°–140°	140°–160°
Excellent fan-on temperature range: No change needed.	Fair: Consider fan-control replacement if fan-off temperature is also borderline.	Poor: Adjust or replace fan control.

Fan-on Temperature

If the forced-air heating system doesn't meet these standards, consider the following improvements.

- Clean or change dirty filters. Clean air-conditioning coils.
- Clean the blower, increase fan speed, and improve ducted air circulation. *See page 235.*
- Adjust fan control to conform to these standards, or replace the fan control if adjustment fails. Some fan controls aren't adjustable.
- Adjust the high limit control to conform to the above standards, or replace the high limit control.

After adjustments, measured temperature rise should be no lower than manufacturer's specifications or the listed minimum values in *Table 8-3 on page 198.*

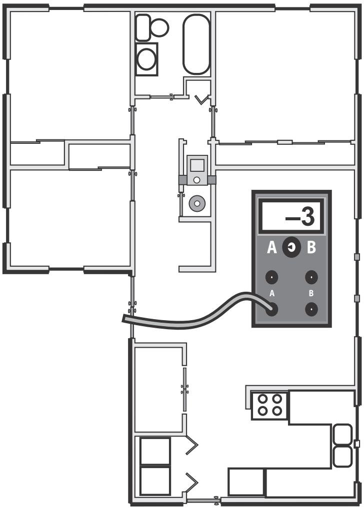
Unbalanced Supply-Return Airflow Test

Closing interior doors often isolates supply registers from return registers in homes with central returns. This imbalance often pressurizes bedrooms and depressurizes central areas with return registers. These pressures can drive air leakage through the building shell, create moisture problems, and bring pollutants in from the crawl space, garage, or CAZ.

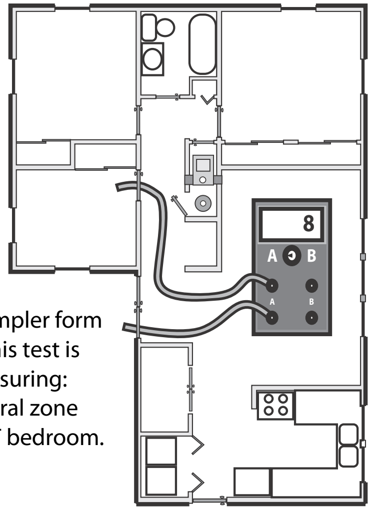
The following test uses only the air handler and a digital manometer to evaluate whether the supply air is able to cycle back through the return registers. Activate the air handler and close interior doors.

First, measure the pressure difference between the home's central living area and the outdoors with a digital manometer. Then, measure the bedrooms' pressure difference with outdoors. As an simpler alternative, you can measure the pressure difference between the central zone and the bedroom.

If difference between those two measurements is more than ±2.0 pascals with the air handler operating, pressure relief is desirable. To estimate the amount of pressure relief needed, slowly open the bedroom door until the pressure difference drops to below 1 pascal. Estimate the surface area of door opening. This is the area of the permanent opening required to provide pressure relief. Pressure relief may include undercutting the door or installing transfer grilles or jumper ducts.



A simpler form of this test is measuring: central zone WRT bedroom.



Depressurized central zone: The air handler depressurizes the central zone, where the return register is located, when the bedroom doors are closed. This significantly increases air infiltration through the building shell.

Pressurized bedrooms: Bedrooms with supply registers but no return register are pressurized when the air handler is on and the doors are closed. Pressures this high can double or triple air leakage through the building shell.

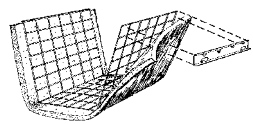
8.12.3 Improving Duct Airflow

Inadequate airflow is a common cause of comfort complaints. When the air handler is on there should be a strong flow of air out of each supply register. Low airflow may mean that a branch is blocked or separated, or that return air is not sufficient. When low airflow is a problem, consider specifying the following obvious improvements as appropriate from your inspection.

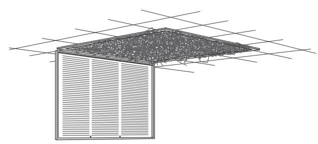
- Clean or change filter.
- Clean furnace blower.
- Clean air-conditioning or heat pump coil. (If the blower is dirty, the coil is probably also dirty.)

- Increase blower speed.
- Make sure that balancing dampers to rooms that need more airflow are wide open.
- Lubricate blower motor, and check tension on drive belt.
- Repair or replace bent, damaged, or restricted registers.
- A Manual D evaluation is required when the ductwork is to be replaced as an ECM.

Panel filter installed in filter slot in return plenum



Washable filter installed on a rack inside the blower compartment.



Panel filter installed in return register

Furnace filter location: Filters are installed on the return-air side of forced air systems. Look for them in one or more of the above locations.

Duct Improvements to Increase Airflow

Consider specifying the following duct changes to increase system airflow and reduce the imbalance between supply and return.

- Clean dirty filters and modify the filter installation to allow easier filter changing, if filter changing is currently difficult.
- Remove obstructions to registers and ducts such as rugs, furniture, and objects placed inside ducts, such as children's toys and water pans for humidification.

- Remove kinks from flex duct, and replace collapsed flex duct and fiberglass duct board.
- Remove excessive lengths of snaking flex duct and stretch the duct to enhance airflow.
- If the blower is dirty, an air conditioning coil, if present, is probably also dirty. Clean the blower and coil.
- Install additional supply ducts and return ducts as needed to provide heated air throughout the building, especially in additions to the building.
- Undercut bedroom doors, especially in homes with single return registers.
- Install registers and grilles where missing and choose low pressure-drop registers.

8.13 Evaluating Duct Air Leakage

Duct air leakage is a major energy-waster in homes where the ducts are located outside the home's thermal boundary in a crawl space, attic, attached garage, or leaky unoccupied basement. When these intermediate zones remain outside the thermal boundary, duct air sealing is usually cost-effective.

Duct leakage within the thermal boundary isn't usually a significant energy problem.

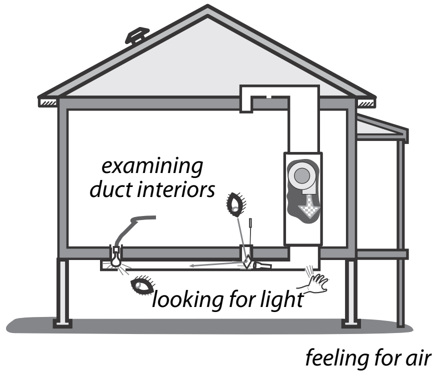
8.13.1 Troubleshooting Duct Leakage

There are several simple procedures for finding the locations of the duct leaks and evaluating their severity.

Finding Duct Leaks Using Touch and Sight

One of the simplest ways of finding duct leaks is feeling with your hand for air leaking out of supply ducts, while the ducts are pressurized by the air handler's blower. Duct leaks can also be located using light. These tests can be used to locate air leaks.

- Use the air handler blower to pressurize supply ducts. Closing the dampers on supply registers temporarily or partially blocking the register with pieces of carpet, magazines, or any object that won't be blown off by the register's airflow increases the duct pressure and make duct leaks easier to find. Dampening your hand makes your hand more sensitive to airflow, helping you to find duct air leaks.



Finding duct air leaks: Finding the exact location of duct leaks precedes duct air sealing.

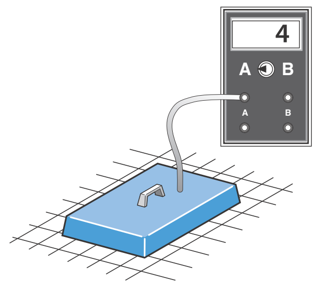
- Place a trouble light, with a 100-watt bulb, inside the duct through a register. Look for light emanating from the exterior of duct joints and seams.
- Determine which duct joints were difficult to fasten and seal during installation. These joints are likely duct-leakage locations.
- Use a trouble light, flashlight, and mirror help you to visually examine duct interiors.

Feeling air leaks establishes their exact location. Ducts must be pressurized in order to feel leaks. You can feel air leaking out of pressurized ducts, but you can't feel air leaking into depressurized return ducts. Pressurizing the home with a blower door forces air through duct leaks, located in intermediate zones, where you can feel the leakage coming out of both supply and return ducts.

Pressure Pan Testing

Pressure pan tests can help both auditors and contractors identify leaky or disconnected ducts, located in intermediate zones. A pressure pan test is required on all site-built and mobile homes evaluated in the Tennessee WAP. With the house depressurized by the blower door to either –25 pascals or –50 pascals with reference to outdoors, pressure pan readings are taken at each supply and return register.

A pressure of –50 pascals is preferred if conditions allow. Pressure pan testing is reliable for homes where the ducts are outside the air barrier.



A pressure pan: Blocks a single register and measures the air pressure behind it, during a blower door test. The magnitude of that pressure is an indicator of duct leakage.

Basements are often part of a home's conditioned living space. In this case, pressure pan testing isn't necessary, although air sealing the return ducts for safety is still very important. If instead, the basement is accessed from the outside and rarely used, the basement may be considered outside the conditioned living space. In this case, open a window or door between the basement and outdoors, and close any door or hatch between conditioned spaces and basement during pressure pan testing.

1. Install blower door and set-up house for winter conditions. Open all interior doors.
2. If the basement is conditioned living space, open the door between the basement and upstairs living spaces. If the basement isn't conditioned living space, close the door between basement and upstairs, and open a basement window.

3. Turn furnace off at the thermostat or main switch. Remove furnace filter, and tape filter slot if one exists. Be sure that all grilles, registers, and dampers are fully open.

4. Temporarily seal any outside fresh-air intakes to the duct system. Seal supply registers in zones that are not intended to be heated — an uninhabited basement or crawl space, for example.

5. Open attics, crawl spaces, and garages as much as possible to the outside so they don't create a secondary air barrier.

6. Connect hose between pressure pan and the input tap on the digital manometer. Leave the reference tap open.

7. With the blower door's manometer reading –25 or –50 pascals, place the pressure pan completely over each grille or register one by one to form a tight seal. Leave all other grilles and registers open when making a test. Record each reading, which should give a positive pressure.

8. If a grille is too large or a supply register is difficult to cover with the pressure pan (under a kitchen cabinet, for example), seal the grille or register with masking tape. Insert a pressure probe through the masking tape and record the reading. Remove the tape after the test, and test the other over-sized registers in the same way.

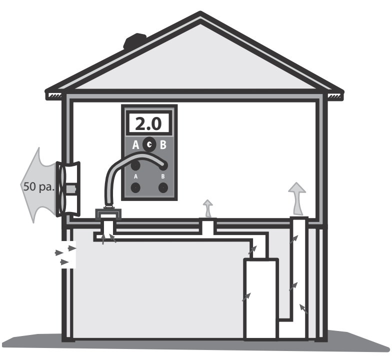
9. Use either the pressure pan or tape to test each register and grille in a systematic way.

Pressure Pan Duct Standards

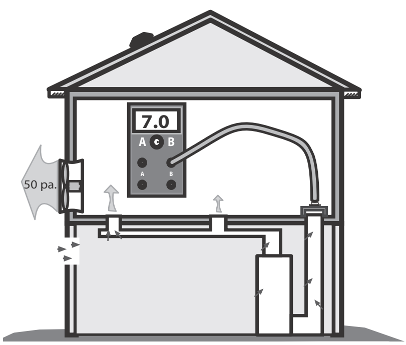
If the ducts are perfectly sealed with no leakage to the outside, no pressure difference (0.0 pascals) will be measured during a pressure-pan test. The higher the pressure reading, the more connected the duct is to the outdoors.

- If three or more readings are greater than 2.0, examine duct system for leaks and repair, especially if ducts are located outside the conditioned living space.
- Following weatherization work, no more than three registers should have pressure-pan readings greater than 1.0 pascals. No single reading shall be greater than 3.0 pascals.
- The best weatherization providers won't accept readings greater than 1.0 pascals.

Pay particular attention to registers connected to ducts that are located in areas outside the conditioned living space. Unconditioned spaces containing ductwork include attics, crawl spaces, garages, and unoccupied basements. Also pay attention to registers attached to stud cavities or panned joists used as return ducts. Leaky ducts located outside the conditioned living space may lead to pressure-pan readings in excess of 30 pascals if they have large holes.



Pressure pan test: A pressure pan reading of 2 indicates moderate duct air leakage in the supply ducts.



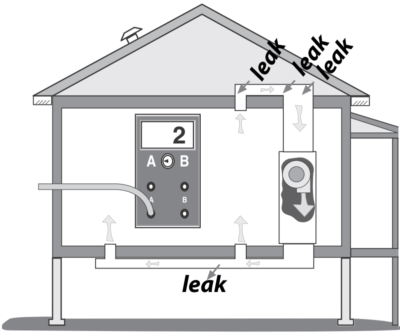
Problem return register: A pressure reading of 7 pascals indicates major air leakage near the tested register.

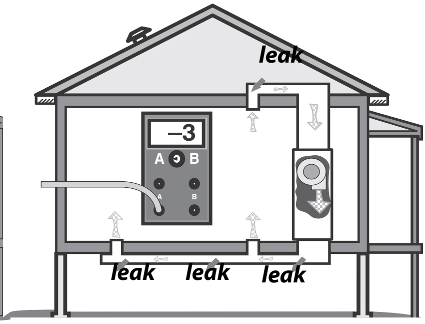
8.13.2 Measuring House Pressure Caused by Duct Leakage

The following test measures pressure differences between the main body of the house and outdoors, caused by duct leakage. Pressure difference greater than +2.0 pascals or more negative than –2.0 pascals should be corrected because of the shell air leakage that the pressure differences create.

The following house-pressure testing procedure is useful for both testing in and testing out as part of an energy audit or weatherization job.

1. Set-up house for winter conditions. Close all windows and exterior doors. Turn-off all exhaust fans.
2. First, open all interior doors, including door to basement.
3. Measure the baseline house-to-outdoors pressure difference and zero it out using the baseline procedures described in *"Adjusting for Baseline Pressure" on page 69*.
4. Turn on air handler.
5. Measure the house-to-outdoors pressure difference. This test indicates dominant duct leakage as shown here.





Dominant return leaks: When return leaks are larger than supply leaks, the house shows a positive pressure with reference to the outdoors.

Dominant supply leaks: When supply leaks are larger than return leaks, the house shows a negative pressure with reference to the outdoors.

A positive pressure indicates that the return ducts (which pull air from leaky intermediate zones) are leakier than the supply ducts. A negative pressure indicates that the supply ducts (which push air into intermediate zones through their leaks) are leakier than return ducts. A pressure at or near zero indicates equal supply and return leakage or else little duct leakage.

8.14 Sealing Duct Leaks

Ducts are often considered part of the thermal boundary because they are full of house air. Return ducts that are connected to attics, crawl spaces, or attached garages can create a lot of air leakage.

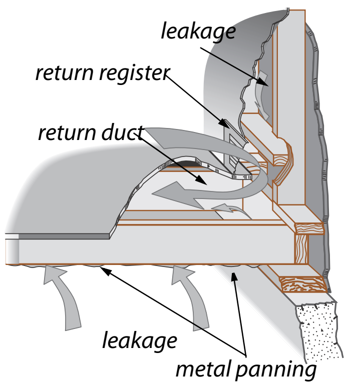
Ducts located outside the thermal boundary or in an intermediate zone like a ventilated attic or crawl space should be sealed. The following is a list of duct leak locations in order of their relative importance. Leaks nearer to the air handler are exposed to higher pressure and are more important than leaks further away.

Auditors and contractors must use all available diagnostic resources to accurately identify duct leakage locations to ensure that this duct energy waste is properly addressed in the Tennessee WAP.

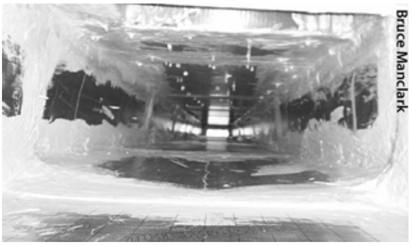
8.14.1 Sealing Return Ducts

Return leaks are important for combustion safety and for efficiency. Use the following techniques to seal return ducts.

- ✓ First, seal all return leaks within the combustion zone to prevent this leakage from depressurizing the combustion zone and causing backdrafting.
- ✓ Seal panned return ducts using mastic to seal all cracks and gaps within the return duct and register.
- ✓ Seal leaky joints between building materials composing cavity return ducts, like panned floor cavities and furnace return platforms. Remove the panning to seal cavities, containing joints in building materials.



Panned floor joists: These return ducts are often very leaky and may require removing the panning to seal the cavity.



Lining a panned cavity: Foil-faced foam board, designed for lining cavities is sealed with duct mastic to provide an airtight return.

- ✓ Carefully examine and seal leaks at transitions between panned floor joists and metal trunks that change the direction of the return ducts. You may need a mirror to find some of the biggest return duct leaks in these areas.

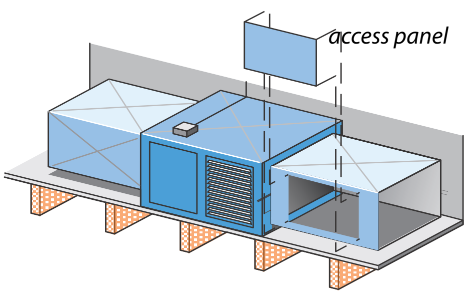
✓ Seal filter slots with an assembly that allows easy changing of filters.

✓ Seal the joint between the furnace and return plenum with silicone caulking or foil tape.

8.14.2 Sealing Supply Ducts

Inspect the following areas and seal them appropriately.

✓ Plenum joint at air handler: These joints may have been difficult to fasten and seal because of tight access. Seal these thoroughly even if it requires cutting an access hole in the plenum. Use silicone caulking or foil tape instead of mastic and fabric mesh here for future access — furnace replacement, for example.



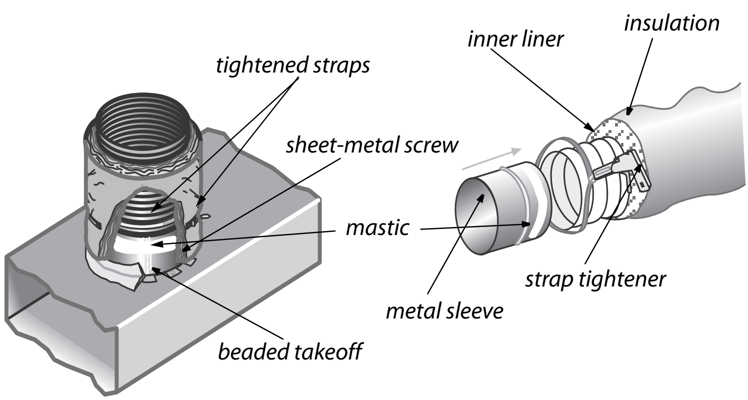
Plenums, poorly sealed to air handler: When air handlers are installed in tight spaces, plenums may be poorly fastened and sealed. Cutting a hole in the duct may be the only way to seal this important joint.

Sectioned elbows: Joints in sectioned elbows known as gores are usually quite leaky and require sealing with duct mastic.

✓ Joints at branch takeoffs: These important joints should be sealed with a thick layer of mastic. Fabric mesh tape is a plus for new installations or when access is easy.

✓ Joints in sectioned elbows: Known as gores, these are usually leaky and require sealing with duct mastic.

- ✓ Tabbed sleeves: Attach the sleeve to the main duct with 3-to-5 screws and apply mastic plentifully. Or better, remove the tabbed sleeve and replace it with a manufactured take-off.
- ✓ Flexduct-to-metal joints: Apply a 2-inch band of mastic to the end of the metal connector. Clamp the flexduct's inner liner with a plastic strap, using a strap tensioner. Clamp the insulation and outer liner with another strap.
- ✓ Flex duct must be replaced when it is punctured, deteriorated, or otherwise damaged.
- ✓ Deteriorating ductboard facing: Replace ductboard, preferably with metal ducting when the facing deteriorates because this condition leads to massive air leakage.



Flexduct joints: Flexduct itself is usually fairly airtight, but joints, sealed improperly with tape, can be very leaky. Use methods shown here to make flexduct joints airtight.

- ✓ Consider sealing off supply and return registers in unoccupied basements or crawl spaces.
- ✓ Seal penetrations made by wires or pipes traveling through ducts.

- ✓ Support ducts and duct joints with duct hangers at least every 5 feet or as necessary to prevent sagging of more than one-half inch.

8.14.3 Duct Boots, Registers, and Chases

Caulk or foam the joint between the boot and the ceiling, wall, or floor between conditioned and unconditioned areas.

If chase opening is large, seal with a rigid barrier such as plywood or drywall, and seal the new barrier to ducts with caulk or foam. Smaller cracks between the barrier and surrounding materials may be foamed or caulked.

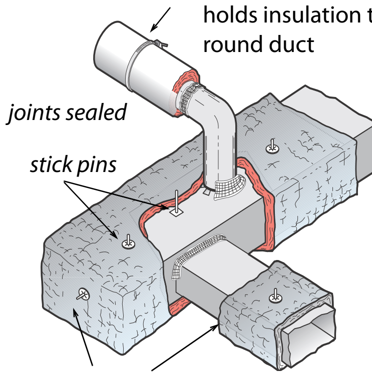
8.14.4 Materials for Duct Sealing

Duct mastic is the preferred duct-sealing material because of its superior durability and adhesion. Apply at least $^{1}/_{16}$-inch thick and use reinforcing mesh for all joints wider than $^{1}/_{8}$-inch or joints that may experience movement.

Joints should rely on mechanical fasteners to prevent joint movement or separation. Don't expect tape to hold a duct joint together nor expected to resist the force of compacted insulation or joint movement. Aluminum foil or cloth duct tape are not good materials for duct sealing because their adhesive often fails. Tape should be covered with mastic to prevent its adhesive from drying out and failing if used for duct-sealing.

8.15 Duct Insulation

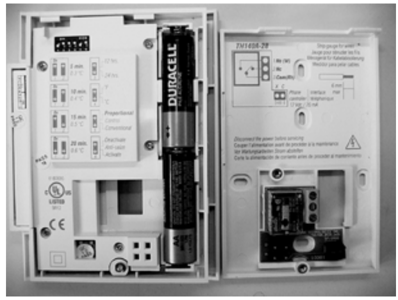
Specify insulation for supply ducts that run through unconditioned areas outside the thermal boundary such as crawl spaces, attics, and attached garages with a minimum of R-6 vinyl-faced or foil-faced duct insulation. Don't insulate ducts that run through conditioned areas unless they cause overheating in winter or condensation in summer. Follow the best practices listed below for installing insulation.



Duct insulation: Supply ducts, located in unheated areas, should be insulated to a minimum of R-6.

- Duct sealing should always be completed before duct insulation.
- Insulation should cover all exposed supply ducts, without significant areas of bare duct left uninsulated.
- Specify fastening insulation with mechanical means such as stick pins or plastic straps.
- Note: Tape can be effective for covering joints in the insulation to prevent air convection, but tape fails when expected to resist the force of the insulation's compression or weight. Outward clinch staples can help hold the insulation facing and tape together.

8.16 Programmable Thermostats



Inside a programmable thermostat: In addition to the instructions on the exterior of this thermostat are instructions inside for setting the heat anticipator.

A programmable thermostat may be a big energy saver if the building occupant understands how to program it. A programmable thermostat won't save any energy if occupants already control day and night temperatures effectively.

If the existing thermostat is replaced as a part of weatherization work, discuss programmable thermostats with occupants. If they are willing to use a programmable thermostat, then install one. Train occupants on the use of the thermostat and leave a copy of manufacturer's directions with them before or after installation.

Many models of programmable thermostats have settings that are selected from inside the thermostat. These include the heat anticipator setting, which adjusts the cycle length of the heating or cooling system.

8.17 Electric Heat

Electricity is a more convenient form of energy than gas or other fuels, but it is considerably more expensive. Electric heaters are usually 100% efficient at converting the electricity to heat in the room where they are located.

8.17.1 Electric Baseboard Heat

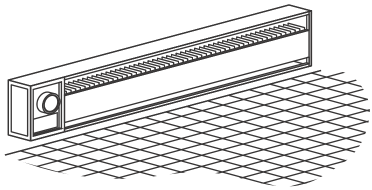
Electric baseboard heaters are zonal heaters controlled by thermostats within the zone they heat. Electric baseboard heat can result in relatively lower energy costs in many homes, if residents take advantage of the ability to zone.

Baseboard heaters contain electric resistance heating elements encased in metal pipes. These pipes extend the length of the unit and are surrounded by aluminum fins to aid heat transfer. As air within the heater is heated, it rises into the room. This draws cooler air into the bottom of the heater.

- Make sure that the baseboard heater sits at least an inch above the floor to facilitate good air convection.
- Clean fins and remove dust and debris from around and under the baseboard heaters as often as necessary.
- Avoid putting furniture directly against the heaters. To heat properly, there must be space for air convection.

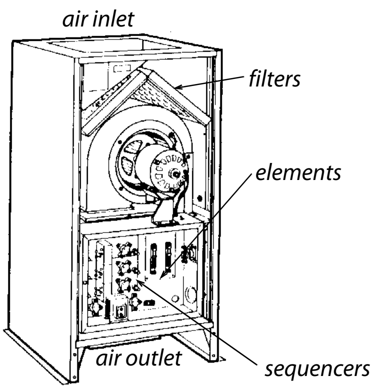
There are two kinds of built-in electric baseboard heaters: strip-heat and liquid-filled. Strip-heat units are less expensive than liquid-filled, but they don't heat as well. Strip-heat units release heat in short bursts, as the temperature of the heating elements rises to about 350°F. Liquid-filled baseboard heaters release heat more evenly over longer time periods, as the element temperature rises only to about 180°F.

The line-voltage thermostats used with baseboard heaters sometimes do not provide good comfort. This is because they allow the temperature in the room to vary by 2°F or more. Newer, more accurate thermostats are available. Programmable thermostats for electric baseboard heat employ timers or a resident-activated button that raises the temperature for a time and then automatically returns to setback. Some baseboard systems use low-voltage thermostats connected to relays that control baseboard heaters in rooms.



Electric Baseboard: Electric baseboard is more efficient than an electric furnace and sometimes even outperforms a central heat pump because it is easily zoneable. The energy bill is determined by the habits of the occupants and the energy efficiency of the building.

8.17.2 Electric Furnaces



Electric Furnace: A squirrel-cage blower blows air over 3 to 6 electric resistance coils and down into the plenum below the floor.

Electric furnaces are the most expensive way to heat a building, combining the most expensive energy source with an often inefficient ducted air distribution system. Electric furnaces heat air moved by its fan over several electric-resistance heating elements. Electric furnaces have three to six elements — 3.5 to 7 kW each — that work like the elements in a toaster. The 24-volt thermostat circuit energizes devices called sequencers that bring the 240 volt heating elements on in stages when the thermostat calls for heat. The variable speed fan switches to a higher speed as more elements engage to keep the air temperature stable.

8.17.3 Central Heat-Pump Energy Efficiency

An air-source heat pump is almost identical to an air conditioner, except for a reversing valve that allows refrigerant to follow two different paths, one for heating and one for cooling.

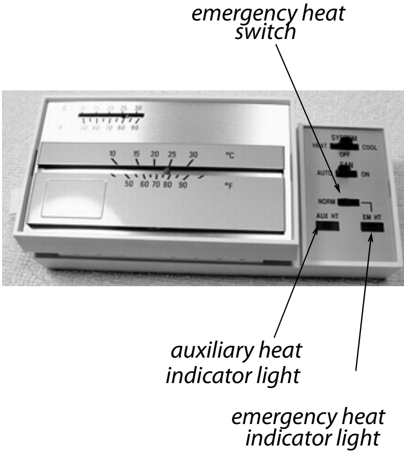
Like air conditioners, air-source heat pumps are available as centralized units with ducts or as room units. Heat pumps are 1.5 to 3 times more efficient than electric furnaces. Heat pumps can provide competitive comfort and value with combustion furnaces, but they must be installed with great care and planning.

Heat pumps are also equipped with auxiliary electric resistance heat, called strip heat. The energy efficiency of a heat pump is largely determined by how much of the heating load can be handled by the compressor without the aid of the strip heat.

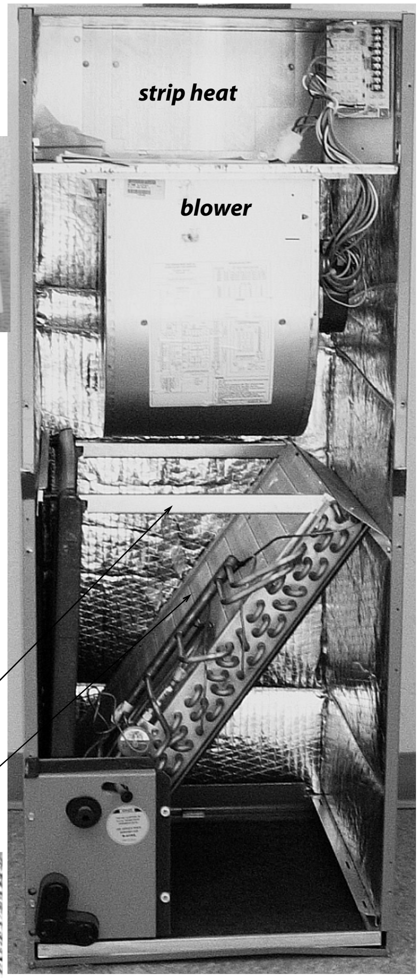
Evaluating Central Heat Pumps

Consider the following quick evaluation steps for central heat pump systems.

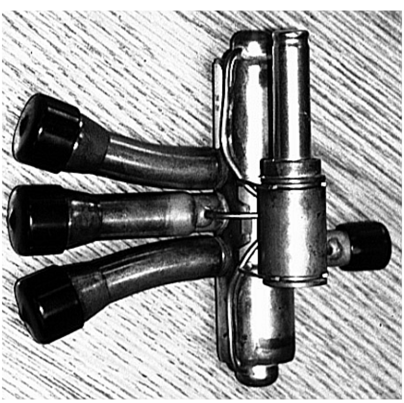
- Heat pumps should have two-stage thermostats designed for heat pumps. The first stage is compressor heating and the second stage is the auxiliary strip heat.
- Look for a supply-air temperature of between 90° and 100° during normal heating operation. A higher temperature than this range means that the auxiliary heat may be on.
- Check for strip-heat operation at the thermostat by observing whether the auxiliary heat or emergency heat indicator lights are on. These indicator lights shouldn't be on during normal heating operation.
- Supply and return ducts should be sealed and insulated after the airflow has been verified as adequate.



Heat pump thermostat: These should have two indicator lights, one for auxiliary heat and one for emergency heat.

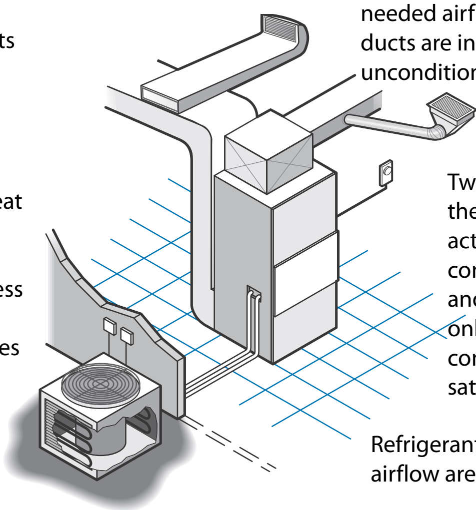


Heat pump: This upflow indoor air handler contains a blower, indoor coil, strip heat, and filter bracket.



Reversing valve: The outdoor unit contains a reversing valve installed near the compressor.

Most residential central heat pumps are split systems with the indoor coil and air handler indoors and outdoor coil and compressor outdoors. Individual room heat pumps are more efficient since they have the advantage of no ducts and are factory-charged with refrigerant. The illustration shows features of an energy-efficient heat pump installation.



Coil is cleaned every year. Weeds, grass and shrubs shouldn't grow within 3 feet. Verify that no airflow restrictions exist above the outdoor unit.

8.17.4 Room Heat Pumps

Room heat pumps can provide all or part of the heating and cooling needs for small homes. These one-piece room systems (also known as terminal systems) look like a room air conditioner, but provide heating as well as cooling. They can also provide ventilation air when neither heating nor cooling are required. They mount in a window or through a framed opening in a wall.

Room heat pumps can be a good choice for replacing existing unvented gas space heaters. Their fuel costs may be somewhat higher than gas furnaces, though they are safer and require less maintenance than combustion appliances. Room heat pumps also gain some overall efficiency because they heat a single zone and don't have the delivery losses associated with central furnaces and ductwork. If they replace electric resistance heat, they consume only one-half to one-third the electricity to produce the same amount of heat.

Room heat pumps draw a substantial electrical load, and may require 240-volt wiring. Provide a dedicated circuit that can support the equipment's rated electrical input. Insufficient wiring capacity can result in dangerous overheating, tripped circuit breakers, blown fuses, or motor-damaging voltage drops. In most cases a licensed electrician should confirm that the house wiring is sufficient. Don't run portable heat pumps or any other appliance with extension cords or plug adapters.

8.18 Evaluating Central Air-Conditioning Systems

Problems with air conditioning often go hand in hand with problems with the building shell. Window shading, attic insulation, and air leakage should be evaluated together with air-conditioner performance.

1. *See "Attic and Roof Insulation" on page 135.*
2. *See "Air Leakage Testing" on page 213.*

Air conditioning system replacement, repair, or installation using health and safety funds is allowed in homes of at-risk occupants where climate conditions warrant.

8.18.1 Evaluating Forced-Air System Airflow

The following four installation-related problems are characteristic of central air-conditioning and heat-pump systems.

1. Inadequate airflow: The ducts, especially return ducts are too small.
2. Duct air leakage: Ducts leak conditioned air into attics, crawl spaces, and attached garages.
3. Incorrect charge: The system has too much or too little refrigerant, causing it to operate inefficiently.
4. Oversizing: The air conditioner or heat pump is too large, and it cycles too often, wasting energy on each cycle.

Refrigerant-charge testing and adjustment should be done after airflow measurement and improvement and after duct testing and sealing. The logic behind this sequence is that airflow should be adequate before duct sealing is done in case you have to add or enlarge ducts. Manufacturers recommend that adequate airflow be verified before charge is checked and adjusted.

Table 8-17: Compiled Research Results on HVAC Performance[a]

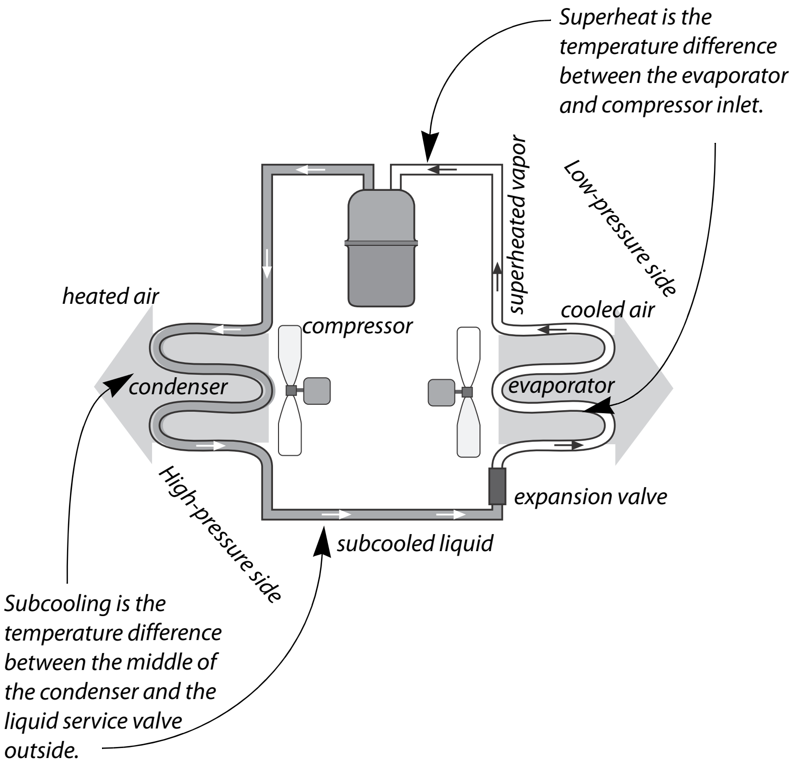
Installation-Related Problem	%[b]	Savings Potential
Duct air leakage (Ave. 270 CFM_{25})[c]	70%	17% Ave.
Inadequate airflow	70%	7% Ave.
Incorrect charge	74%	12% Ave.
Oversized by 50% or more	47%	2–10%

a. Report sponsored by Environmental Protection Agency (EPA) and compiled from research from Multiple Field Studies
b. Percent of tested homes found with a significant problem.
c. The number of homes of the duct-leakage studies was around 14,000; the number for the other problems was over 400 each.

8.18.2 Central Air-Conditioner Inspection

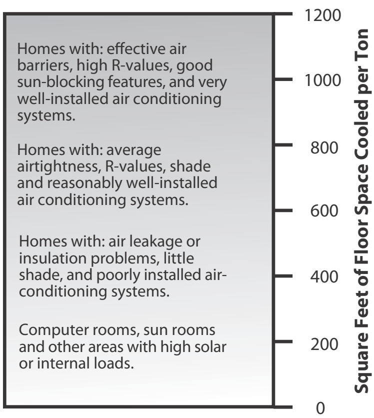
Air conditioners move vast amounts of air, and that air contains dust. The filter in the air handler is supposed to catch all the dust, but depending on how good the filter and its mounting assembly are, some dirt gets through or around the filter. The condenser coil outdoors isn't protected by a filter and is usually quite dirty.

- ✓ Inspect the condenser coil and know that it is probably dirty even if it looks relatively clean on the outside. Take a flat toothpick and shove it in between the fins to the other side. Can you scrape dirt out from between the fins? Can you push the toothpick through the dirt?
- ✓ Specify cleaning the condenser with either with a biodegradable coil cleaner or by special high-pressure spray, used by professional coil cleaning contractors.
- ✓ Inspect the filter slot in the air handler or the filter grille in the return air registers. Do the filters completely fill their opening? Is the filter dirty?
- ✓ Inspect the blower in the air handler after disconnecting power to the unit. Can you remove significant dirt from one of the blades with your finger? If the blower is dirty, then the evaporator coil is also dirty.
- ✓ Insist that the blower and evaporator be thoroughly cleaned. Contractors should use an indoor coil cleaner if a cleanser is used.


Superheat is the temperature difference between the evaporator and compressor inlet.
superheated vapor
Low-pressure side
heated air
compressor
cooled air
condenser
evaporator
expansion valve
High-pressure side
subcooled liquid
Subcooling is the temperature difference between the middle of the condenser and the liquid service valve outside.

8.18.3 Air-Conditioner Sizing

Correct sizing is accomplished through sizing calculations, typically performed by an auditor or HVAC specialist using a computer sizing program.



Air-Conditioner Sizing: An energy-efficient home shouldn't need more than a ton of air-conditioner capacity per 1000 square feet of floor area.

The number of square feet of floor space that can be cooled by one ton of refrigeration capacity is a measure of the home's energy efficiency. Air-conditioners provide cooling most cost-effectively when they are sized accurately and run for long cycles. The auditor's cooling-cost reduction strategy should focus on making the home more energy efficient and making the air conditioner work more efficiently. Making the home more efficient would involve shading, insulation and air leakage reduction. Making the air conditioner more efficient would involve either service or repair to remove installation-related flaws.

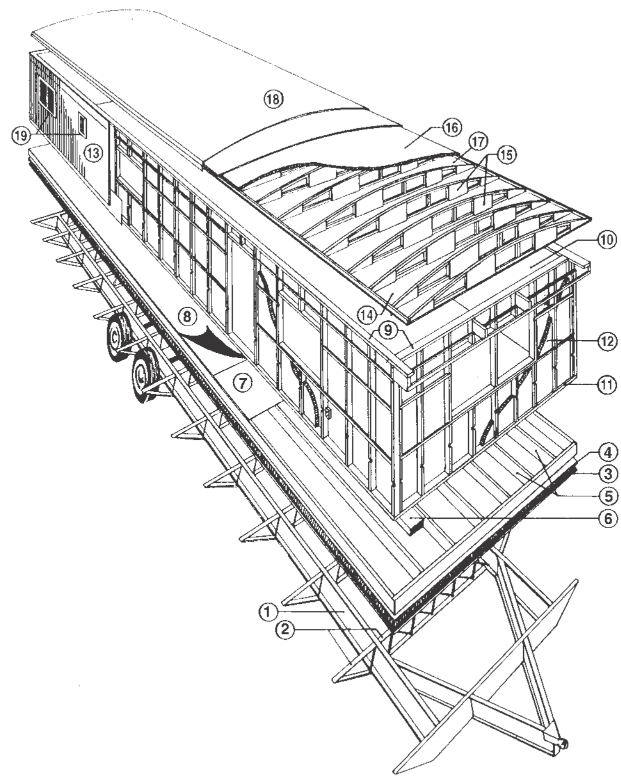
8.18.4 Duct Leakage and System Airflow

Duct leakage and poor airflow afflict most air-conditioning systems unfortunately. The testing and mitigation of these problems was covered earlier.

1. *See "Evaluating Duct Air Leakage" on page 237.*
2. *See "Ducted Air Distribution" on page 230.*

Chapter 9: Mobile Homes

Mobile homes typically use more energy per square foot than site-built homes. Fortunately, their consistent construction makes them easy to weatherize. Mobile homes aren't governed by the International Residential Code 2009, allowing the contractor more flexibility in treating mobile homes' unique problems.



Typical Components of a Mobile Home: 1–Steel chassis. 2–Steel outriggers and cross members. 3–Underbelly. 4–Fiberglass insulation. 5–Floor joists. 6–Heating/air conditioning duct. 7–Decking. 8–Floor covering. 9–Top plate. 10–Interior paneling. 11–Bottom plate. 12–Fiberglass insulation. 13–Metal siding. 14–Ceiling board. 15–Bowstring trusses. 16–Fiberglass insulation. 17–Vapor barrier. 18–Galvanized steel one-piece roof. 19–Metal windows.

Insulation upgrades save the most energy in mobile homes, though sealing shell and duct air leaks presents good opportunities, too. Mobile home heating replacement is often cost-effective when a customer's energy usage is high.

9.1 Mobile Home Air Sealing

The location and relative importance of mobile home air leaks was a mystery before blower doors. Some mobile homes are fairly airtight, and others are very leaky. Air leakage serves as ventilation in most mobile homes. Observe the Minimum Ventilation Guidelines outlined in *"Evaluating Home Ventilation Levels" on page 74*.

A duct airtightness tester, which pressurizes the ducts and measures their air leakage, is the best way to measure and evaluate duct air sealing. *See "Evaluating Duct Air Leakage" on page 237.* For simply locating duct leaks, the blower door used in conjunction with a pressure pan does a good job. *See "Pressure Pan Testing" on page 239.*

Most mobile home duct sealing is performed through the belly. This work is more difficult once the belly has be re-insulated. Inspect the ductwork and seal any major leaks, such as disconnected trunk lines, before insulating the belly.

Table 9-1: air sealing Locations & Typical CFM_{50} Reduction

air sealing Procedure	Typical CFM_{50} Reduction
Patching large air leaks in the floor, walls and ceiling	200–900
Sealing floor cavity used as return-air plenum (*See "Floor return air" on page 265.*)	300–900
Sealing leaky water-heater closet	200–600
Sealing leaky supply ducts	100-500
Installing tight interior storm windows	100-250
Caulking and weatherstripping	50–150

Mobile home shell air leakage is often substantially reduced when insulation is installed in roofs, walls, and belly cavities. Prioritize your efforts by performing these tasks in this order.

1. Assess the insulation levels. If adding insulation is cost-effective, perform the usual pre-insulation air sealing measures that also prevent spillage of insulation out of the cavity.
2. Install cavity insulation. Perform duct sealing first if the belly is to be insulated.
3. Re-check the air leakage rate.
4. Perform additional air sealing as needed.

9.1.1 Shell Air Leakage Locations

Blower doors have pointed out the following shell locations as the most serious air leakage sites.

- ✓ Plumbing penetrations in floors, walls, and ceilings. Water-heater closets with exterior doors are particularly serious Air Leakage problems, having large openings into the bathroom and other areas
- ✓ Torn or missing underbelly, exposing flaws in the floor to the ventilated crawl space
- ✓ Large gaps around furnace and water heater chimneys
- ✓ Severely deteriorated floors in water heater compartments
- ✓ Gaps around the electrical service panel box, light fixtures, and fans
- ✓ Joints between the halves of double-wide mobile homes and between the main dwelling and additions

Note: Window and door air leakage is more of a comfort problem than a serious energy problem.

9.1.2 Duct Leak Locations

Blower doors and duct testers have pointed out the following duct locations as the most serious energy problems.

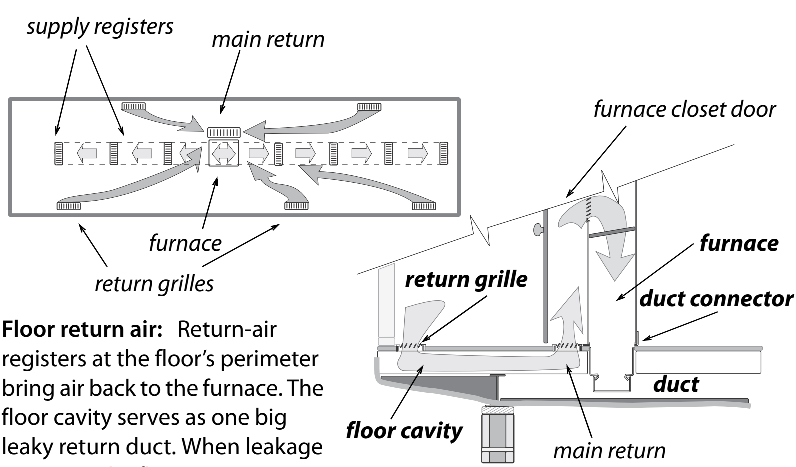
- ✓ Floor and ceiling cavities used as return-air plenums — These floor return systems should be eliminated and replaced with return-air through the hall or a large grille in the furnace-closet door.
- ✓ Joints between the furnace and the main duct — The main duct may need to be cut open from underneath to access and seal these leaks between the furnace, duct connector, and main duct. With electric furnaces you can access the duct connector by removing the resistance elements. For furnaces with empty A-coil compartments, you can simply remove the access panel to seal the duct connector.
- ✓ Joints between the main duct and the short duct sections joining the main duct to a floor register
- ✓ Joints between register boots and floor
- ✓ The poorly sealed ends of the duct trunk, which often extend beyond the last supply register
- ✓ Disconnected, damaged or poorly joined crossover ducts
- ✓ Supply and return ducts for outdoor air conditioner units
- ✓ Holes cut in floors by tradesmen.
- ✓ New ductwork added to supply heat to room additions

Be sure to seal floor penetrations and ductwork before performing any belly repair. Pollutants in the crawl space such as mold and dust will be disturbed by repair work and can be drawn into the home by duct depressurization.

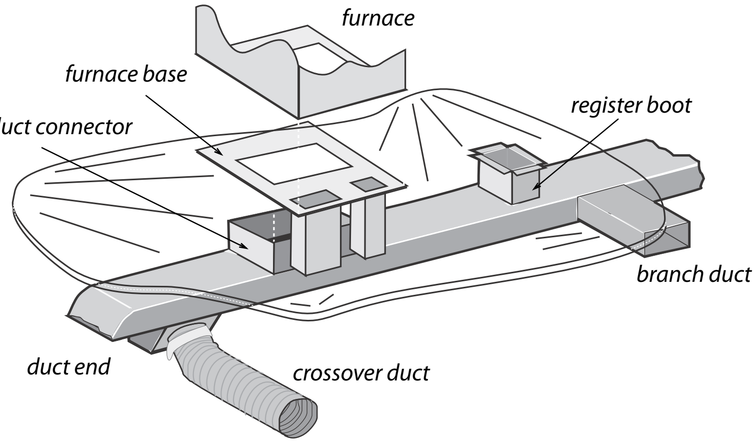
9.1.3 Belly Pressure Test

Mobile home supply duct leaks pressurize the belly cavity. Follow these steps to perform this rough test to determine if duct leaks are present and their general location.

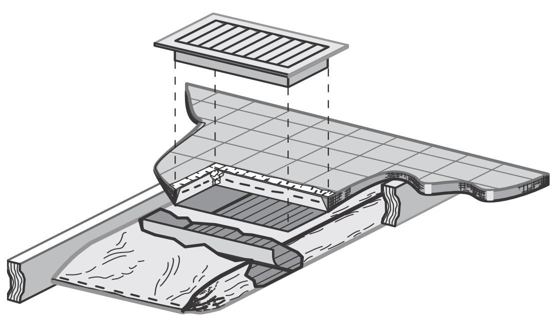
- ✓ Repair the rodent barrier.
- ✓ Turn on the air handler.
- ✓ Insert a manometer hose into the belly through the rodent barrier and test the pressure with-reference-to the outdoors.
- ✓ Start near the furnace, and work your way toward the ends alongside the trunk line. A pressure rise gives you a rough idea of the location of leaks, size of leaks, and tightness of the nearby rodent barrier.
- ✓ Repair the ducts and re-test.



Floor return air: Return-air registers at the floor's perimeter bring air back to the furnace. The floor cavity serves as one big leaky return duct. When leakage is serious, the floor return system should be eliminated.



Mobile home ducts: Mobile home ducts leak at their ends and joints — especially at the joints beneath the furnace. The furnace base attaches the furnace to the duct connector. Leaks occur where the duct connector meets the main duct and where it meets the furnace. Branch ducts are rare, but easy to find, because their supply register isn't in line with the others. Crossover ducts are found only in double-wide and triple-wide homes.



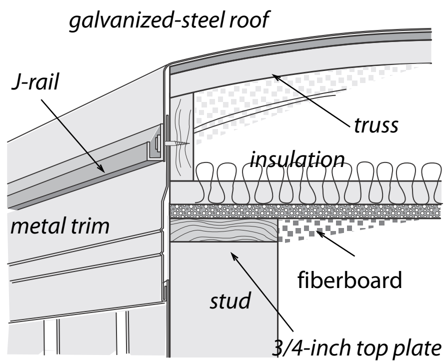
Sealing the end of the main duct: The main duct is usually capped or crimped loosely at each end, creating a major air leakage point. Seal this area and improve airflow by installing a sheet metal ramp, accessed through the last register, inside the duct. Seal the ramp to the ductwork with metal tape and silicone or mastic.

9.2 Mobile Home Insulation

Address all significant moisture problems before insulating. The most important single moisture-control measure is installing a ground-moisture barrier. *See "Moisture Problems" on page 290. See also "Ground Moisture Barrier" on page 157.*

9.2.1 Insulating Mobile Home Roof Cavities

Blowing a closed mobile home roof cavity is similar to blowing a closed wall cavity, only the insulation doesn't have to be as dense. Use fiberglass blowing wool because cellulose is too heavy and absorbs water too readily for use around a mobile home's lightweight sheeting materials.



Bowstring roof details: Hundreds of thousands of older mobile homes were constructed with these general construction details.

There are three common and effective methods for blowing mobile home roof cavities.

1. Cutting a square hole in the metal roof and blowing fiberglass through a flexible fill-tube.
2. Disconnecting the metal roof at its edge and blowing fiberglass through a rigid fill-tube.
3. Blowing fiberglass through holes drilled in the ceiling.

Preparing to Blow a Mobile Home Roof

Perform these steps before insulating mobile home roofs.

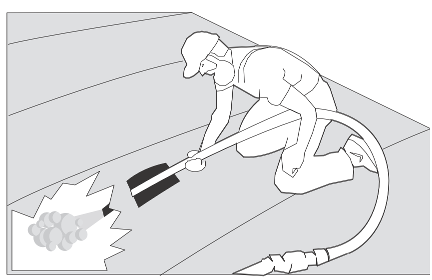
- ✓ Reinforce weak areas in the ceiling.
- ✓ Inspect the ceiling and seal all penetrations.
- ✓ Take steps to maintain safe clearances between insulation and recessed light fixtures and ceiling fans.

Blowing Through the Top

Blowing through the roof top does a good job of filling the critical edge area with insulation, and the patches are easy to install if you have the right materials. It is important to complete the work during good weather, however, since the roof will be vulnerable to rain or snow during the job.

If the roof contains a strongback running the length of the roof, the holes should be centered over the strongback, which is usually near the center of the roof's width. A strongback is a 1-by-4 or a 1-by-6, installed at a right angle to the trusses near their center point, that adds strength to the roof structure.

1. Cut 10-inch square holes at the roof's apex on top of every second truss. Each square hole permits access to two truss cavities.
2. Use a 2-inch or 2-1/2-inch diameter fill-tube. Insert the fill-tube and push it forcefully out toward the edge of the cavity.
3. Blow fiberglass insulation into each cavity.
4. Stuff the area under each square hole with a piece of unfaced fiberglass batt

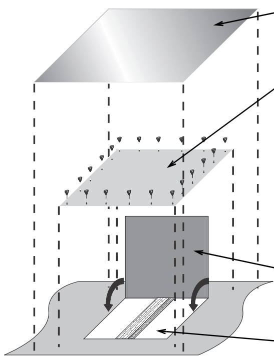


Roof-top insulation: Blowing fiberglass insulation through the roof top is effective at achieving good coverage and density on almost any metal roof.

so that the finished roof patch will stand a little higher than the surrounding roof.

5. Patch the hole with a 14-inch-square piece of stiff galvanized steel, sealed with roof cement and screwed into the existing metal roof.

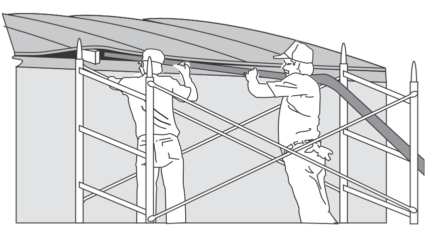
6. Cover the first patch with a second patch, consisting of an 18-inch-square piece of foil-faced butyl rubber.



Square roof patch: An 18-inch square of foil-faced butyl rubber covers a base patch of galvanized steel, which is cemented with roof cement and screwed with self-drilling screws.

Blowing a Mobile Home Roof from the Edge

Erect scaffold to be performed this procedure safely and efficiently. Mobile home metal roofs are usually fastened only at the edge, where the roof joins the wall.



Roof-edge blowing: Use a rigid fill tube to blow insulation through the roof edge. This avoids making holes in the roof itself, though this process requires much care in refastening the roof edge.

1. Remove the screws from the metal j-rail at the roof edge. Also remove staples or other fasteners, and scrape off putty tape.

2. Pry the metal roof up far enough to insert a 2-inch-diameter, 10- to 14-foot-long rigid fill-tube. Two com-

mon choices are steel muffler pipe and aluminum irrigation pipe. Inspect the cavity with a bright light to identify any wires or piping that could be damaged by the fill tube.

3. Blow insulation through the fill-tube into the cavity. Turn off the insulation-material feed and blower on the blowing machine when the tube is a couple feet from the roof edge, in order to avoid blowing insulation out through the opening in the roof edge. Stuff the last foot or two with unfaced fiberglass batts.

4. Fasten the roof edge back to the wall using galvanized roofing nails, a new metal j-rail, new putty tape, and larger screws. The ideal way to re-fasten the metal roof edge is with air-driven galvanized staples, which is the way most roof edges were attached originally.

The re-installation of the roof edge is the most important part of this procedure. Putty tape must be replaced and installed as it was originally. This usually involves installing a layer of putty tape or a bead of high quality caulk under the metal roof and another between the metal roof edge and the j-rail.

The advantages of blowing through the edge is that if you have the right tools, including a powered stapler, this method can be very fast and doesn't require cutting into the roof. The disadvantages of this procedure are that you need scaffolding to work at the edges, and it won't work on roof systems with a central strongback that stops the fill tube from reaching all the way across the roof.

Blowing a Mobile Home Roof from Indoors

The advantage to this method is that you are indoors, out of the weather. The disadvantages include being indoors where you can make a mess — or worse, damage something.

Blowing the roof cavity from indoors requires the drilling of straight rows of 3-inch or 4-inch holes and blowing insulation into the roof cavity through a fill tube.

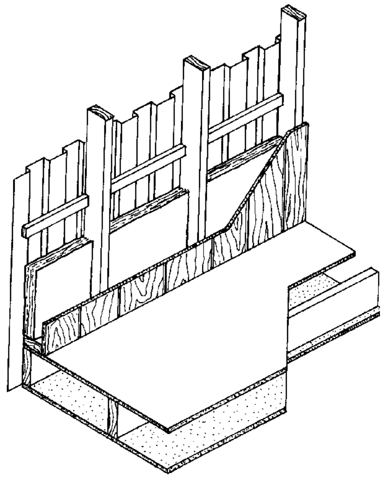
Follow this procedure.

1. Drill a 3-inch or 4-inch hole in an unseen location to discover whether the roof structure contains a strongback that would prevent blowing the roof cavity from a single row of holes.
2. Devise a way to drill a straight row of holes down the center of the ceiling. If a strongback exists, drill two rows of holes at the quarter points of the width of the ceiling.
3. Insert a flexible plastic fill tube into the cavity, and push it as far as possible toward the edge of the roof.
4. Fill the cavity with tightly packed fiberglass insulation.
5. Cap the holes with manufactured plastic caps. Care must be taken not to damage the holes so that the plastic hole covers fit properly. You can also install a piece of painted wood trim over the line of holes.

Blowing through the ceiling: The contractor pushes the fill-tube into the cavity and out near the edge of the roof. The holes are drilled in a straight line for appearance sake.

9.2.2 Mobile Home Sidewall Insulation

The sidewalls of many mobile homes are not completely filled with insulation. This reduces the nominal R-value of the existing wall insulation because of convection currents and air leakage. Consider the following steps for adding insulation to partially filled mobile home walls.



Standard mobile home construction: 2-by-4 walls and 2-by-6 floor joists are the most common construction details

Adding insulation to mobile home walls: A contractor uses a fill tube to install more insulation in a partially filled mobile home wall.

1. Check the interior paneling and trim to make sure they are securely fastened to the wall. Repair holes in interior paneling and caulk cracks at seams to prevent indoor air from entering the wall. Note the location of electrical boxes and wire to avoid hitting them when you push the fill tube up the wall.

2. Remove the bottom horizontal row of screws from the exterior siding. If the vertical joints in the siding interlock, fasten the bottom of the joints together with $^1/_2$-inch sheet metal screws to prevent the joints from coming apart. Pull the siding and existing insulation

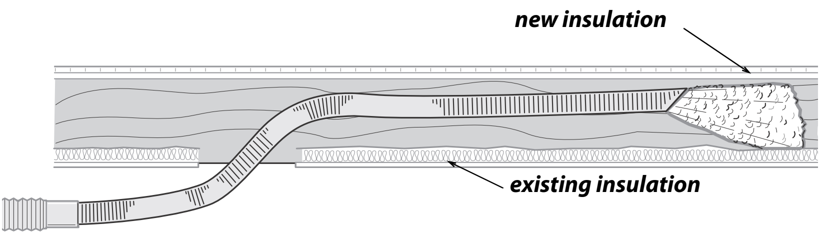
away from the studs, and insert the fill tube into the cavity with the point of its tip against the interior paneling.

3. Push the fill tube up into the wall cavity until it hits the top plate of the wall. The tube should go in to the wall cavity 7-to-8 feet. It is important to insert the tube so that its natural curvature presses its tip against the interior paneling. When the tip of the fill tube, cut at an angle, is pressed against the smooth paneling, it is least likely to snag the existing insulation on its way up the wall. If the fill tube hits a belt rail or other obstruction, twisting the tube will help its tip get past the obstruction.
4. Stuff a piece of fiberglass batt into the bottom of the wall cavity around the tube to prevent insulation from blowing out of the wall cavity. Leave the batt in-place at the bottom of the wall, when you pull the fill tube out of the cavity. This piece of batt acts as temporary gasket for the hose and insulates the very bottom of the cavity after the hose is removed. This batt also eliminates the need to blow fiberglass insulation all the way to the bottom, preventing possible spillage and overfilling. If you happen to overfill the bottom of the cavity, reach up inside the wall to pack or remove some fiberglass insulation, particularly any that lies between the loose siding and studs.
5. Draw the tube down and out of the cavity about 6 inches at a time. Listen for the blower fan to indicate strain from back-pressure in the wall. Watch for the fiberglass insulation to slow its flow rate through the blower hose at the same time. Also watch for slight bulging of the exterior siding. These signs tell the installer when to pull the tube down.

6. Carefully refasten the siding using the same holes. Use screws that are slightly longer and thicker than the original screws.

9.2.3 Mobile Home Floor Insulation

Mobile home floor insulation is a good energy-saving measure in cool climates. The original insulation is usually fastened to the bottom of the floor joists, leaving much of the cavity uninsulated and subject to convection currents. This greatly reduces the insulation's R-value. Blown-in belly insulation also tends to control duct leakage.



Blowing bellies: A flexible fill-tube, which is significantly stiffer than the blower hose, blows fiberglass insulation through a hole in the belly from underneath the home.

Preparing for Mobile Home Floor Insulation

Prior to installing floor insulation, always perform these repairs.

- ✓ Repair plumbing leaks.
- ✓ Tightly seal all holes in the floor.
- ✓ Inspect and seal ducts.
- ✓ Repair the rodent barrier.
- ✓ Install a ground-moisture barrier in the crawl space if the site is wet.

Insulating the Floor

Two methods of insulating mobile home floors are common. Blown fiberglass is recommended over cellulose for either method.

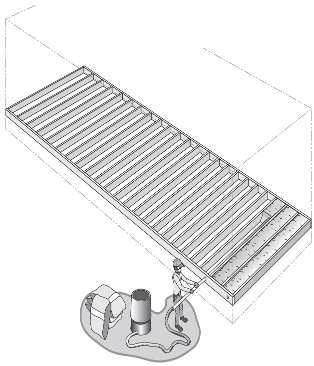
1. Drilling through the 2-by-6 rim joist and blowing fiberglass through a rigid fill tube into the belly.
2. Blowing fiberglass insulation through a flexible fill tube or a rigid fill tube into the underbelly.

Blowing a floor through the belly: The contractor inserts a rigid fill tube through the belly to blow insulation into the floor cavity and underbelly.

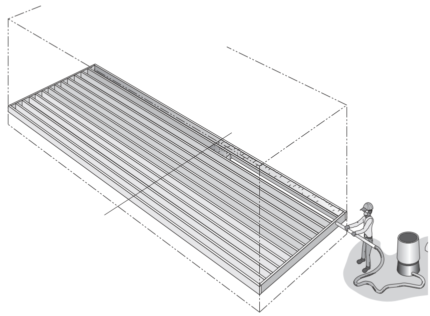
First repair all holes in the belly. Use mobile home belly-paper, silicone sealant, and stitch staples. Use these same patches over the holes cut for fill-tubes. Screw wood lath over weak areas if needed.

When blowing through holes from underneath the home, consider blowing through damaged areas before patching them.

Identify any plumbing lines, and avoid installing insulation between them and the living space if freezing could be an issue. This may require running a piece of belly-paper under the pipes, and insulating the resulting cavity, to include them in the heated envelope of the home.



Blowing crosswise cavities: Blowing insulation into belly is easy if the floor joists run crosswise. However, the dropped belly requires more insulation than a home with lengthwise joists.



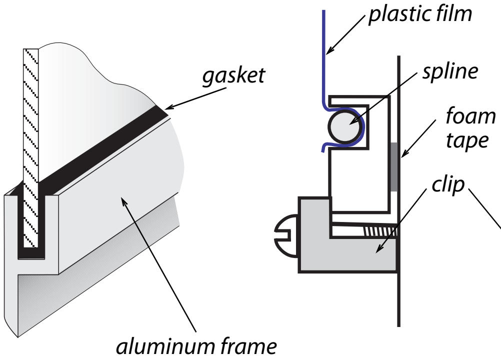
Blowing lengthwise cavities: Floors with lengthwise joists can rarely be filled completely from the ends because of the long tubing needed. The middle can be filled from underneath.

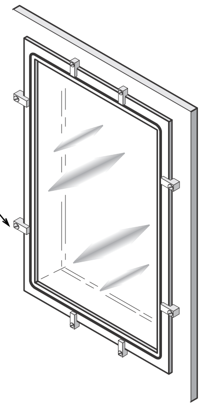
Unfaced fiberglass batts may also be used to insulate floor sections where the insulation and belly are missing. The insulation should be supported by lath, twine, or insulation supports. This is a good approach when it is not cost-effective to insulate the entire belly.

9.3 Mobile Home Windows and Doors

Repairing or replacing mobile home windows and doors is often part of a mobile home weatherization job. Installing storm windows or replacing existing windows is expensive per square foot and isn't as cost-effective as insulation. However, storm windows and replacement windows are all energy conservation measures for mobile homes that are worth considering.

9.3.1 Mobile Home Storm Windows



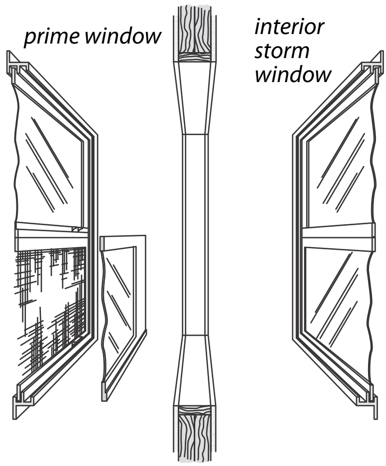


Glass interior storms: Traditional mobile home storm windows have aluminum frames glazed with glass.

Plastic storms: Some newer Storm window designs use a lightweight aluminum frame and flexible or rigid plastic glazing.

Interior storm windows are common in mobile homes. These stationary interior storms serve awning and jalousie windows. Sliding interior storm windows pair with exterior sliding prime windows.

- ✓ Interior storm windows double the R-value of a single-pane window. They also reduce infiltration, especially in the case of leaky jalousie prime windows.
- ✓ Consider repairing existing storm windows rather than replacing them unless the existing storm windows cannot be re-glazed or repaired.
- ✓ When sliding primary windows are installed, use a sliding storm window that slides from the same side as the primary window. Sliding storm windows stay in place and aren't removed seasonally, and are therefore less likely to be lost or broken.



Mobile home double window: In mobile homes, the prime window is installed over the siding outdoors, and the storm window is installed indoors.

9.3.2 Replacing Mobile Home Windows

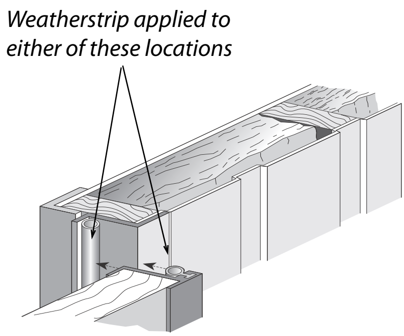
Replacement windows should have lower U-factors than the windows they are replacing. Inspect condition of rough opening members before replacing windows. Replace deteriorated, weak, or waterlogged framing members.

Prepare replacement window by lining the perimeter of the inner lip with $^1/_8$-inch thick putty tape. Caulk exterior window frame perimeter to wall after installing window.

See "Window Energy Specifications" on page 169.

9.3.3 Mobile Home Doors

Mobile home doors come in two basic types: the mobile home door and the house-type door. Mobile home doors swing outwardly, and house-type doors swing inwardly. House-type doors are available with pre-hung storm doors included.



Mobile home door: Mobile home doors swing outwardly and have integral weatherstrip.

9.4 Cool Roofs for Mobile Homes

Cool roof coatings reduce summer cooling costs and improve comfort by reflecting solar energy away from the home's roof and slowing the flow of heat into the home. They are shown to reduce overall cooling costs by 10-20%, and are a good choice for mobile homes or site-built homes with low slope or flat roofs. Cool roof coatings are usually bright white, and must have a reflectivity of at least 60% to meet the ENERGY STAR or equivalent requirement for cool roof coatings.

Cool roof coatings are usually water-based acrylic elastomers, and are applied with a roller. They can be applied over most low-sloped roofing such as metal, built-up asphalt, bitumen, or single ply membranes. Some underlying materials require a primer to get proper adhesion-check the manufacturer's recommendations for asphalt-shingle roofs.

Surface preparation is critical when applying any coating. The underlying roofing materials must be clean so the coating will stick. Repairs should be performed if the existing roofing is cracked or blistered. Roof coating will not stick to dirty or greasy surfaces, and they cannot be used to repair roofs in poor conditions. Observe the following specifications when installing cool roof coatings.

- ✓ Install the coating when dry weather is predicted. Rain heavy dew, or freezing weather, if it happens within 24 hours of installation, will weaken the coating's bond to the underlying roofing.
- ✓ Protect any nearby windows, siding, or automobiles from splatters. For roller application, use a large brush for the edges, and a shaggy 1 to 1 1/2-inch roller on a 5- or 6- foot pole for the field. Run the coating up the roof jacks and other penetrations to help seal these areas. Install at least two coats, with second coat applied in the opposite direction to the first to get more complete coverage. Allow a day for drying between coats.
- ✓ Clean the roof of debris and loose or detach roofing material.
- ✓ Wash the roof with a water/try-sodium phosphate (tsp) solution, or comparable mildew-cide, and scrub brush. Better yet, use a pressure washer.
- ✓ Buy the highest quality coatings, and look for those that are specifically formulated as mobile home roof coatings.
- ✓ Reinforce any open joints around skylights, pipe flashing, roof drains, wall transitions, or HVAC equipment. For build-up asphalt or bitumen roofs, repair any cracks, blisters, or de-laminations. Use polyester fabric and roof coating for these reinforcements and repairs by dipping fabric patches in the roof coating and spreading them over the existing roofing, or by laying dry fabric into a layer of wet coating. Smooth the patches down with a broad-knife or squeegee to remove bubbles or wrinkles. Allow any repairs to cure for 1 to 2 days before applying the topcoat.
- ✓ For metal roofs, sand any rusted areas down to sound metal. Install metal patches over any areas that are rusted through, followed by polyester patches as described above.

9.5 Mobile Home Skirting

The primary purpose of skirting is to keep animals out of the crawl space. Skirting must be vented to reduce moisture accumulation in many climates, so there isn't much value in insulating it.

Installation and repair of mobile home skirting is seldom cost-effective. Locate the thermal boundary at the floor of mobile homes. Mobile home skirting is not an approved ECM in the Tennessee WAP. This information is provided for the reader's greater understanding.

CHAPTER 10: HEALTH AND SAFETY

This chapter introduces some of the most pressing hazards that your clients face in their homes, as well as those you face at work.

When you discover serious safety problems in a customer's home, you should inform the customer about the hazards and suggest how to eliminate them. Major hazards and potentially life-threatening conditions should be corrected before you begin work in the dwelling, unless you are making the corrections as part of the weatherization work scope.

Avoiding hazards in the workplace should be the highest priority for workers.

Customer Health and Safety

House fires, carbon-monoxide poisoning, moisture problems, and lead-paint poisoning are the most important customer-related health and safety problems that are related to building repair work.

- ✓ Ask occupants to reveal known or suspected health concerns, and take extra precautions based on occupant sensitivity to environmental hazards.
- ✓ Inspect the home for fire hazards such as improperly installed electrical equipment, flammable materials stored near combustion appliances, or malfunctioning heating appliances. Discuss the problems with the client, and perform repairs if possible.
- ✓ Test combustion appliances for carbon monoxide and related hazards. Also test the ambient air for carbon monoxide. Investigate and eliminate these hazards. *See "Essential Combustion Safety Tests" on page 208.*
- ✓ Find moisture problems, and discuss them with the client. Never make moisture problems worse. *See page 290.*

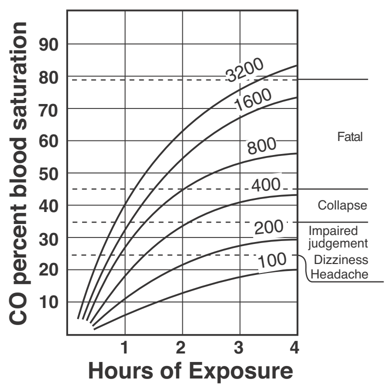
✓ Follow the EPA Repair, Renovation, and Painting rules when working on homes built before 1978. Practice effective dust containment in all weatherization projects. *See page 311.*

Worker Health and Safety

In the worker-safety section at the end of this chapter, we discuss the most statistically dangerous hazards present in the weatherization workplace and how to avoid these hazards. Hazards include: driving, falls, back injuries, cuts, chemical exposure, repetitive stress, and electrical shocks.

10.1 Carbon Monoxide (CO)

The EPA's suggested maximum 8-hour CO exposure is 9 ppm in room air. CO at or above 9 ppm is often linked to malfunctioning combustion appliances within the living space, although cigarette smoking or automobile exhaust are also common CO sources.



Effects of CO: This graph's 6 curves represent different CO exposure levels in parts per million.

10.1.1 Causes of Carbon Monoxide

CO is often linked to unvented gas space heaters, kerosene space heaters, backdrafting vented space heaters, gas ranges, leaky wood stoves, and motor vehicles idling in attached garages or near the home. Central furnaces and boilers that backdraft may also lead to high levels of CO.

CO is normally tested near the flame or at the exhaust port of the heat exchanger. CO is usually caused by one of the following.

- Gas appliances that are overfired compared to their rated input.
- Backdrafting of combustion gases smothering the flame.
- Flame interference by an object (a pan over a gas burner on a range top, for example).
- Inadequate combustion air.
- Flame interference by rapidly moving air.
- Misalignment of the burner, causing a distorted flame.
- Blockage in the flue or heat exchanger.

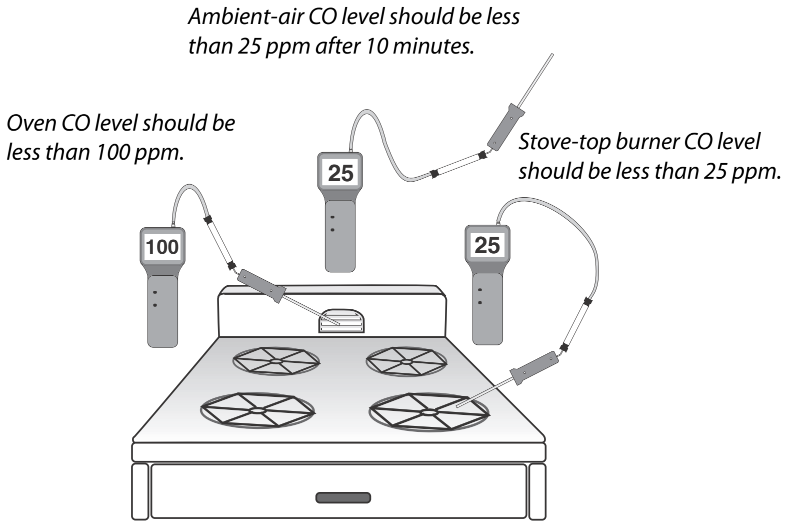
Work with service technicians to identify and correct these problems.

Testing for Carbon Monoxide

The most common CO-testing instruments are electronic sensors with a digital readout in parts per million (ppm). Follow the manufacturer's recommendations on zeroing the meter — usually by operating the meter in outdoor air. CO testing equipment usually needs to be re-calibrated every 6 months or so, using factory-specified procedures.

Air-free CO measurement combines CO and O_2 sensing with a calculation to determine the CO concentration in undiluted flue gases. Air-free CO readings prevent technicians from thinking that moving the testing probe or diluting CO are solutions. *See "Carbon Monoxide (CO) Testing" on page 208.*

10.1.2 Gas Range and Oven Safety



CO from range and oven: Measure CO at burners from 8″ away. Measure CO at oven in undiluted flue gases.

Gas ranges and ovens can produce significant quantities of CO in a kitchen. Overfiring, dirt buildup, and foil installed around burners are frequent causes of CO. Oven burners are likely to produce CO even when not obstructed by dirt or foil. Test the range and oven for safety following these steps and take the recommended actions before or during weatherization.

1. Test each stove-top burner separately, using a digital combustion analyzer or CO meter. Hold the probe about 8 inches above the flame.
2. Clean and adjust burners producing more than 25 parts per million (ppm). Burners may have an adjustable gas control.
3. Turn on the oven to bake on high temperature. Sample the CO level in exhaust gases at the oven vent and in the ambient air after 10 minutes.

If the CO reading is over 100 ppm or if the ambient-air reading rises to 25 ppm or more during the test, discontinue testing. Take action to reduce CO, including cleaning the oven, removing aluminum foil, adjusting the burner's adjustable gas control, or replacing the range and oven. Many range and oven burners are equipped with adjustable needle-and-seat valves. Many ranges also have an adjustable gas regulator that services the entire unit.

Note: Following the guidance of Weatherization Program Notice 11-6, addressing Weatherization Health and Safety Guidance with an effective date of January 12, 2011 it is no longer permissible to replace appliances with health and safety funds. Repair and cleaning is an allowed health and safety expense. Therefore, replacement of gas ranges and ovens is not permissible with WAP Health and Safety funds.

In the event that combustion safety issues arise with the gas range or oven during the initial audit of the home that require replacement of the unit and the owner/resident is not able to address the issues, the home may need to be deferred when no other funding sources are available to address the issues. When hazards are identified, clients must be informed in writing and the document must be signed by the client and a copy maintained in the client file.

Advice to Clients about Ranges and Ovens

Advise the occupants of the following important operating practices.

- ✓ Never install aluminum foil around a range burner or oven burner.
- ✓ Never use a range burner or gas oven as a space heater.
- ✓ Open a window, and turn on the kitchen exhaust fan when using the range or oven.
- ✓ Keep range burners and ovens clean to prevent dirt from interfering with combustion.

✓ Burners should display hard blue flames. Yellow or white flames, wavering flames, or noisy flames should be investigated by a trained gas technician.

✓ Buy and install a CO alarm, and discontinue use of the range and oven if the CO level rises above 9 ppm.

CO Mitigation

When the measured CO level is 200 ppm as measured or 400 ppm air-free, measured either at the oven vent while the oven is lit or one foot above the burners while they are lit, the following two steps are required.

1. Make adjustments to reduce the CO level, or recommend a service call by a gas combustion specialist to adjust the fuel-air mixture of the burners.
2. Install a CO alarm in the kitchen.

In the case of CO measurements greater than the above standards, arrange an immediate service call to identify and correct the cause of CO production. Install an exhaust fan with a capacity of 100 cubic feet per minute (cfm) in the kitchen.

Kitchen exhaust fans installed as part of weatherization work must vent to outdoors and be equipped with the following.

- Solid metal ducting to the outdoors.
- A weatherproof termination fitting.
- A backdraft damper, installed in the fan housing or termination fitting.
- Noise rating of less than 2 sones.

Advanced 4-Speed Range Fan: Lower speeds for continuous ventilation and higher ones for spot ventilation.

10.2 Smoke and Carbon Monoxide Alarms

All homes should have at least one smoke alarm on each level, including one near the combustion zone and at least one near the bedrooms. Carbon monoxide (CO) alarms are appropriate whenever the CO hazard is considered a likely occurrence.

Combination CO and smoke alarms are now available. Single-function alarms or combination alarms can be interconnected for whole-house protection.

Customers should be educated about the purpose and features of the alarms and what to do if an alarm sounds. Following are specifications for installing CO alarms and smoke alarms.

10.2.1 Smoke Alarms

Observe these specifications when installing smoke alarms.

- ✓ Install according to manufacturer's instructions.
- ✓ If mounted on a wall, mount from 4 to 12 inches from the ceiling.
- ✓ If mounted on a ceiling, mount at least 6 inches from the nearest wall.
- ✓ Connect to a circuit that is energized at all times.

Don't install smoke alarms in these situations.

- Within 12 inches of exterior doors and windows
- With an electrical connection to a switched circuit
- With a connection to a ground-fault circuit interrupter (GFCI)

10.2.2 CO Alarms

CO alarms should be installed in all homes with unvented space heaters and in all homes where a furnace return air could back-draft a space heater, wood stove, fireplace, or water heater.

Observe these specifications when installing CO alarms.

- ✓ Install according to the manufacturer's instructions
- ✓ Connect to a circuit that is energized at all times

Don't install CO alarms in these cases.

- In a room that may get too hot or cold for alarm to function properly
- Within 5 feet of a combustion appliance, vent, or chimney
- Within 5 feet of a storage area for vapor-producing chemicals
- Within 12 inches of exterior doors and windows
- Within a furnace closet or room
- With an electrical connection to a switched circuit
- With a connection to a ground-fault interrupter circuit (GFCI)

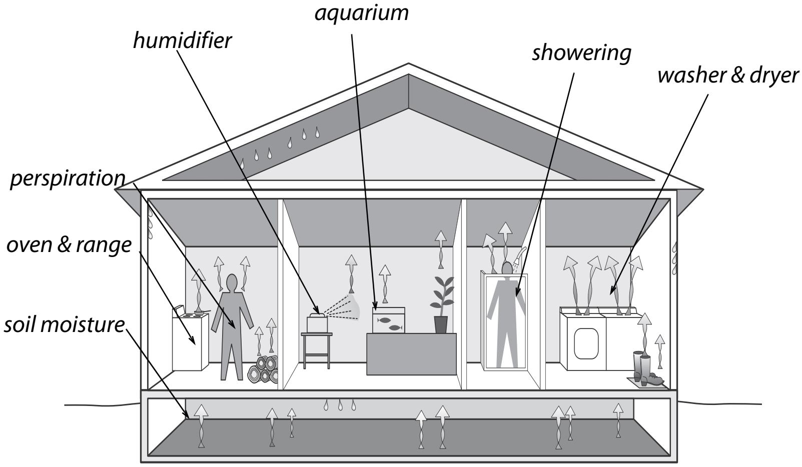
10.3 Moisture Problems

Moisture causes billions of dollars worth of property damage, sickness, and high energy bills each year in American homes. Water damages building materials by dissolving glues and mortar, corroding metal, and nurturing pests like mold, dust mites, and insects. These pests, in turn, cause many cases of respiratory distress.

Water reduces the thermal resistance of insulation and other building materials. High humidity also increases air-conditioning costs because the air conditioner removes moisture from the air to provide comfort.

The most common sources of moisture are leaky roofs and damp foundations. Other critical moisture sources include dryers venting indoors, showers, cooking appliances, and unvented gas appliances like ranges or decorative fireplaces.

Climate is also a major contributor to moisture problems. The more rain, extreme temperatures, and humid weather a region experiences, the more its homes are vulnerable to moisture problems.



Moisture sources: Household moisture can often be controlled at the source by informed and motivated occupants, who work to control moisture sources like these.

Reducing moisture sources is the first priority for solving moisture problems. Next most important are air and vapor barriers to prevent water vapor from migrating through building cavities. Relatively tight homes need mechanical ventilation to remove accumulating water vapor.

Table 10-1: Moisture Sources and Their Potential Contributions

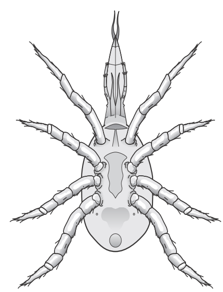
Moisture Source	Potential Amount Pints
Ground moisture	0–105 per day
Unvented combustion space heater	0.5 –20 per hour
Seasonal evaporation from materials	6–19 per day
Dryers venting indoors	4–6 per load
Dish washing	1–2 per day
Cooking (meals for four persons)	2–4 per day
Showering	0.5 per shower

10.3.1 Symptoms of Moisture Problems

Condensation on windows, walls, and other cool surfaces signals high relative humidity and the need to reduce moisture sources. During very cold weather or summer air conditioning, condensation may occur on cold surfaces. This occasional condensation isn't a major problem. However, if condensation is a persistent problem, reduce moisture sources. Adding insulation helps eliminate cold walls, ceilings, or air-conditioning ducts where water vapor condenses.

Moisture problems arise when parts of the building become wet often and stay wet for periods of time. Moisture in organic or porous building materials reaches a threshold that allows pests like mold, dust mites, and insects to thrive. These pests can cause or aggravate asthma, bronchitis, and other respiratory ailments because they produce potent biological allergens.

Rot and wood decay indicate advanced moisture damage. Unlike surface mold and mildew, wood decay fungi penetrate, soften, and weaken wood.



Dust mites: Biological pests create bioaerosols that can cause allergies and asthma.

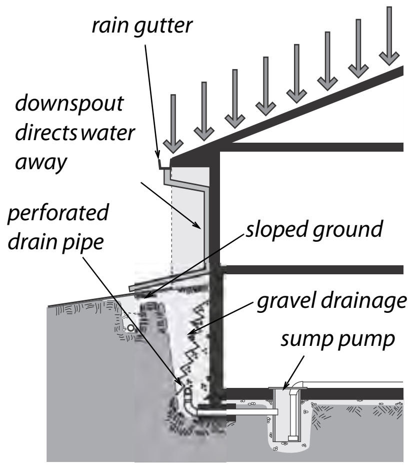
Peeling, blistering, or cracking paint may indicate that moisture is moving through a wall, damaging the paint and possibly also the building materials underneath.

Corrosion, oxidation, and rust on metal are unmistakable signs of moisture problems. Deformed wooden surfaces may appear as the damp wood swells, and later warps and cracks as it dries.

Concrete and masonry efflorescence often indicates excess moisture at the home's foundation. Efflorescence is a white, powdery deposit left by water that moves through masonry and leaves minerals from mortar or the soil behind as it evaporates from the masonry surface.

10.3.2 Preventing Moisture Problems

Preventing moisture problems is the best way to guarantee a building's durability and its occupant's respiratory health. Follow these preventive measures before trying any of the solutions in the next section.



Stopping water intrusion: Take all necessary steps protect homes from water intrusion.

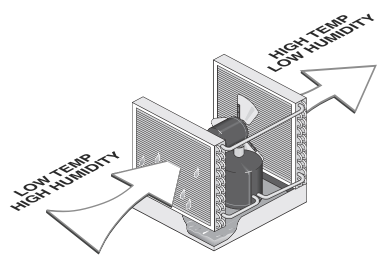
- ✓ In rainy climates, install rain gutters with downspouts that drain roof water away from the foundation. Rainwater flowing from roofs often plays a major role in dampening foundations.
- ✓ A sump pump is the most effective remedy when ground water continually seeps into a basement or crawl space and collects there as standing water. Serious ground-water problems may require excavating and installing drain pipe and gravel to disperse accumulations of groundwater between a home and the underlying soil.
- ✓ Install a ground moisture barrier, which is a piece of heavy plastic sheeting laid on the ground. Black heavy plastic film works well, but tough cross-linked polyethylene is more durable. The edges should be sealed to the foundation walls with urethane adhesive and/or mechanical fasteners. The seams should be sealed as well.

- ✓ Educate customers to avoid excessive watering around the home's perimeter. Watering lawns and plants close to the house can dampen its foundation. In moist climates, keep shrubbery away from the foundation, to allow wind circulation near the foundation.

Solving Moisture Problems

If moisture source reduction isn't adequate to prevent moisture problems, try these solutions after preventive measures are in place.

- ✓ Install or improve air barriers and vapor barriers to prevent air leakage and vapor diffusion from transporting moisture into building cavities. *See page 99.*
- ✓ Add insulation to the walls, floor, and ceiling of a home to keep the indoor surfaces warmer and less prone to winter condensation. During cold weather, well-insulated homes can tolerate higher humidity without condensation than can poorly insulated homes.
- ✓ Insulate air-conditioning ducts to prevent summer condensation.
- ✓ Ventilate the home with drier outdoor air to dilute the more humid indoor air. However, ventilation is only effective when the outdoor air is drier than the inside air, such as in winter. In summer, outdoor air may be more or less humid than indoor air depending on climate and whether the home is air conditioned.



Dehumidifiers: In damp climates, dehumidifiers protect homes from excessive moisture.

- ✓ As a last resort, remove moisture from indoor air by cooling the air to below its dew point with compressor-based air-conditioning systems in summer and dehumidifiers in winter.

10.4 Other Pollutants

Radon and asbestos are also important hazards to both occupants and workers.

10.4.1 Radon

Radon is a dangerous indoor air pollutant that comes from the ground through rocky soil. Studies predict 16,000 lung cancer deaths per year caused by radon.

Energy conservation work usually has little effect on radon concentrations. However, all housing specialists should be aware of radon's danger, radon testing procedures, and radon mitigation strategies.

The EPA believes that any home with a radon concentration above 4 pico-Curies per liter (pC/l) of air should be modified to reduce the concentration. There are several common and reliable tests for radon, which are performed by health departments and private consultants throughout the U.S.

Since radon comes through the soil, mitigation strategies include the following.

- Installing a plastic ground barrier and carefully sealing the seams
- Sealing the walls and floor of the basement
- Ventilating the crawl space or basement to dilute radon
- Depressurizing the ground underneath the basement concrete slab

The first two mitigation strategies may already be prescribed by the weatherization work scope and may help to keep radon levels low, after air-sealing.

10.4.2 Asbestos

Asbestos is classified as a "known carcinogen." Asbestos is found in boiler and steam-pipe insulation, floor tile, siding, roofing, and other building materials. Workers who encounter asbestos in the workplace must be trained to recognize and avoid it. Penalties for mishandling asbestos-containing materials can amount to $25,000 per day.

DOE weatherization policy requires weatherization agencies to observe the following safety precautions regarding asbestos.

- Remove asbestos siding only if you can remove the siding without damaging it. Don't cut or drill asbestos siding.
- Test vermiculite for asbestos, and use air monitoring if asbestos is present in the vermiculite in a home you're weatherizing. Don't remove vermiculite.
- Assume that asbestos is present in old grey-colored pipe insulation and duct insulation. Don't disturb this material; also caution occupants not to disturb this material.
- Contract with certified asbestos testers and abatement specialists to mitigate asbestos problems before or during weatherization, if appropriate.

10.5 Whole-House Ventilation Systems

This section discusses three options for design of whole-house ventilation systems.

✓ Exhaust ventilation

✓ Supply ventilation

✓ Balanced ventilation

The following information is provided to expand the understanding of both auditors and contractors regarding whole-house ventilation systems. Such systems are not currently applicable in the Tennessee WAP. In the event that a home is found to be tight (less than the Target Air-Leakage value) during the pre-audit then no further air-sealing ECM will be prescribed. This may result in the home being deferred if no other ECMs are available in the home. However, starting in January 2012, whole-house ventilation systems will be required as part of air sealing under Tennessee WAP.

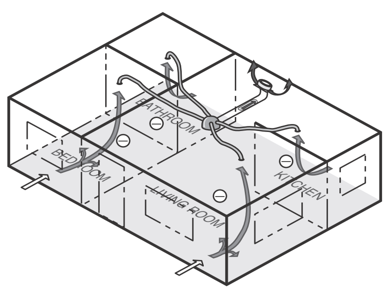
Ventilation systems should always be measured and adjusted to provide only the amount of ventilation required to maintain healthy indoor air quality. Excessive ventilation wastes electricity and heating fuel. *See "Evaluating Home Ventilation Levels" on page 74.*

10.5.1 Exhaust Ventilation

Exhaust ventilation systems employ an exhaust fan to remove indoor air, which is replaced by infiltrating outdoor air.

Installing a two-speed bathroom fan is a common ventilation strategy. The new fan runs continuously on low speed for whole-house ventilation. An built-in occupancy sensor switches the fan automatically to a high speed to remove moisture and odors from the bathroom quickly.

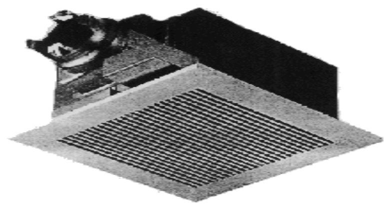
A remote fan that exhausts air from several rooms through ducts (4-to-6 inch diameter) may provide better ventilation for larger more complex homes, compared to an single-point exhaust fan.



Multi-port exhaust ventilation: A multi-port ventilator creates better fresh-air distribution than a single central exhaust fan.

Exhaust ventilation systems create a negative house pressure, drawing outdoor air in through leaks in the shell. This keeps moist indoor air from traveling through building cavities, which would occur with a positive house pressure. The negative house pressure reduces the likelihood of moisture accumulation in building cavities during the winter months in cold climates. In hot and humid climates, however, this depressurization can draw moist outdoor air into the home through building cavities. Therefore we recommend supply ventilation for warm humid climates rather than exhaust ventilation.

Fan Specifications



Specifying exhaust fans: Specify quiet energy-efficient fans.

Continuous ventilation is highly recommended because it simplifies design and control. Continuous ventilation also minimizes depressurization by allowing selection of the minimum-sized fan. Exhaust fans, installed as part of weatherization work, must vent to outdoors and include the following features.

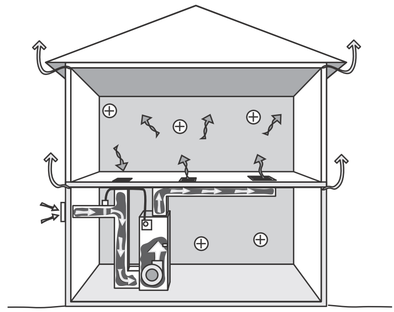
1. The ENERGY STAR® label.
2. A weatherproof termination fitting.
3. A backdraft damper, installed in the fan housing or termination fitting.
4. Noise rating and ventilation efficacy as specified.

Table 10-2: Fan Capacity, Maximum Noise Rating, & Efficacy

Fan Capacity	Noise Rating (sones)	Efficacy cfm/Watt
<50 CFM	<1 sone	2.8
50–100 CFM	<1.5 sones	2.8
>100 CFM	<2.0 sones	2.8

10.5.2 Supply Ventilation

Supply ventilation uses the furnace or heat pump as a ventilator. A 5-to-10 inch diameter duct is connected from outdoors to the furnace's main return duct. This outdoor-air supply duct often has a motorized damper that opens when the air-handler blower operates. This outdoor air is then heated or cooled by the furnace/air conditioner before being delivered to the living spaces.



Supply ventilation: A furnace or heat pump is used for ventilation with a control that ensures sufficient ventilation.

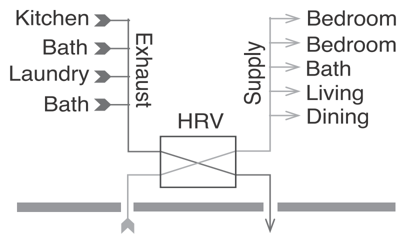
At least one manufacturer makes a control for operating both the furnace blower and the ventilation damper. The control estimates how much ventilation is supplied during heating or cooling and whether the air handler needs to activated for additional ventilation air without heating or cooling.

Supply ventilation, using the home's air handler, is never operated continuously as with exhaust ventilation because the furnace or heat-pump blower is too large and would over-ventilate the home and waste electrical energy. Supply ventilation may not be appropriate for tight homes in very cold climates because supply ventilation can push moist indoor air through exterior walls, where moisture can condense on cold surfaces.

10.5.3 Balanced Ventilation

Balanced ventilation systems exhaust stale air and provide fresh air through a ducted distribution system. Of the three ventilation systems discussed here, balanced systems do the best job of controlling pollutants in the home.

Balanced systems move equal amounts of air into and out of the home. Most balanced systems incorporate heat-recovery ventilators or energy-recovery ventilators that reclaim heat and moisture from the exhaust air stream.



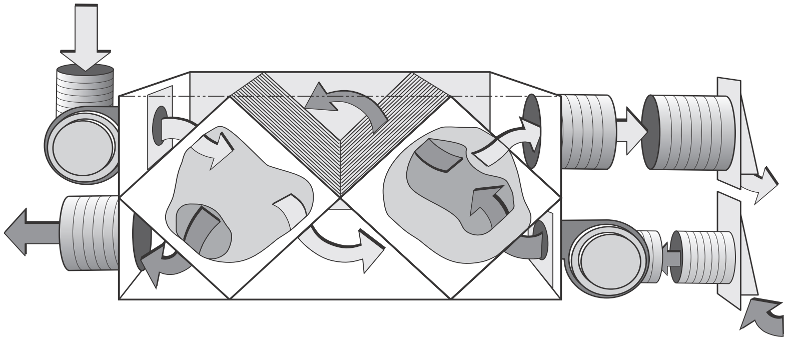
Centralized balanced ventilation: Air is exhausted from areas most likely to contain pollution and fresh air is supplied to living areas.

These complex systems can improve the safety and comfort of home, but a high standard of care is needed to assure that they operate properly. Testing and commissioning is vital during both the initial installation and periodic service calls.

Heat-Recovery and Energy-Recovery Ventilators

The difference between heat-recovery ventilators (HRVs) and energy-recovery ventilators (ERVs) is that HRVs transfer heat only, while ERVs transfer both sensible heat and latent heat (moisture) between airstreams.

HRVs are often installed as balanced whole-house ventilation systems. The HRV core is an air-to-air heat exchanger in which the supply and exhaust airstreams pass one another and exchange heat without mixing.



Heat-recovery ventilator: Heat from the exhaust air heats a plastic or aluminum heat exchanger, which in turn heats the fresh intake air. Two matched fans provide balanced ventilation.

10.5.4 Adaptive Ventilation

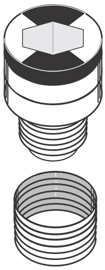
The home's residents can maintain good indoor air quality by using spot ventilation together with opening windows and doors. Depending on climate and season, residents can control natural ventilation to provide clean air, comfort, and energy efficiency.

- ✓ Choose windows and screen doors in strategic locations to ventilate using prevailing winds.
- ✓ Make sure that windows and screen doors, chosen for ventilation, open and close and have effective insect screens.
- ✓ Open windows to provide make-up air when an exhaust fan or the clothes dryer is operating.
- ✓ Understand that dust and pollen may enter through windows or screen doors and consider the consequences.

10.5.5 Electrical Safety

Electrical safety is a basic housing need affecting home weatherization and repair. Observe the following specifications for electrical safety in weatherizing existing homes.

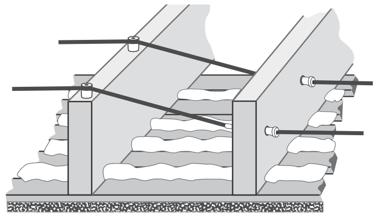
Non contact voltage tester: Test voltage wires near your work area and take action to turn off the circuit if appropriate.



S-type fuse: An S-type fuse prohibits residents from oversizing the fuse and overloading an electrical circuit.

- ✓ Whenever working around wiring, use a non-contact voltage tester to determine whether circuits are live. Turn circuits off at circuit breakers as appropriate.
- ✓ Inspect wiring, fuses, and circuit breakers to ensure that wiring isn't overloaded. Install S-type fuses where appropriate to prevent circuit overloading. Maximum ampacity for 14-gauge wire is 15 amps and for 12-gauge wire is 20 amps.
- ✓ Confirm that all wire splices are enclosed in electrical junction boxes. If you plan to cover a junction box with insulation, mark its location with a sign or flag.
- ✓ Don't allow metal insulation shields to contact wiring.
- ✓ Confirm that the electrical system is grounded to either a ground rod or to a water pipe that has an uninterrupted electrical connection to the ground.

- ✓ Install S-type fuses where appropriate to prevent occupants from installing oversized fuses.



Knob and tube wiring: Obsolete and worn wiring poses a significant fire risk. No insulation can be installed over such wiring.

Knob-and-Tube Wiring

- ✓ Encourage your customers to replace knob-and-tube wiring.
- ✓ Never surround knob-and-tube wiring with insulation covering the wires.

10.6 Worker Health and Safety

The personal health and safety of each employee is vitally important to every company. Injuries are the fourth leading cause of death in the United States, while long-term exposure to toxic materials contributes to sickness, absenteeism, and death of workers. Both of these risk factors are present during weatherization work.

Workplace safety standards have been established by the Occupational Safety and Health Administration (OSHA) and by construction trade organizations; these should be observed by weatherization staff and their contractors. Safety always has priority over other factors affecting weatherization operations.

Some hazards merit the attention because of their statistical importance. Be aware of these most common workplace hazards.

- ✓ Vehicle accidents.
- ✓ Falls.
- ✓ Back injuries.
- ✓ Exposure to hazardous materials.

- ✓ Electrical hazards.
- ✓ Repetitive stress injuries.

10.6.1 Commitment to Safety

It is easy to become complacent about jobsite health and safety if it is not continually emphasized. Do everything possible to create a safe work place by following these practices.

Safety education: Safety meetings are an essential part of a successful safety program.

- ✓ Arrange regular health and safety training.
- ✓ Conduct regular safety meetings.
- ✓ Keep equipment in good condition.
- ✓ Observe all state and federal standards relating to worker health and safety.

Safety requires communication and action. To protect yourself from injury and illness, learn to recognize hazards, communicate with co-workers and supervisors, and take action to reduce or eliminate hazards.

10.6.2 New Employees

New hire: New hires are several times more likely to be injured than are experienced workers.

New employees are several times more likely to injure themselves on the job compared to experienced workers. Before their first day on the job, new employees should learn about safety basics such as proper lifting, safe ladder usage, and safe operation of the power tools they will use on the job.

Be sure to inform new employees about hazardous materials they may encounter on the job. Show new hires the Material Safety Data Sheets (MSDS) required by OSHA for each material.

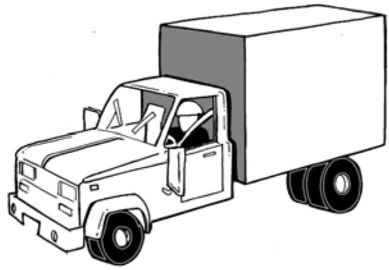
New employees should be required to use this common safety equipment.

- ✓ Proper clothing.
- ✓ Gloves.
- ✓ Respirators.
- ✓ Safety glasses.
- ✓ Hearing protectors.

Alcohol and drugs should be banned from the job. Staff members should be encouraged to refrain from smoking and to stay physically fit.

10.6.3 Driving

According to the Bureau of Labor Statistics, one-third of all occupational fatalities in the United States occur in motor-vehicle accidents. Staff members should organize their errands and commuting to the job site so as to minimize vehicle travel.



Safe vehicles: Maintain vehicles in good repair. Drivers and passengers should always wear seat belts.

Vehicles should be regularly inspected and repaired if necessary. These safety components are most important.

- ✓ Brake system
- ✓ Steering system
- ✓ Horns
- ✓ Headlights
- ✓ Directional signals
- ✓ Backup lights and signals

Always wear seat belts. When traveling to the job, tools and materials should be properly stowed and secured in the cargo area to prevent shifting.

10.6.4 Lifting and Back Injuries

Back injuries account for one out of every five workplace injuries. Most of these injuries are to the lower back and are the result of improper lifting, crawling in tight spaces, and using heavy tools.

Workers often injure their backs by lifting heavy or awkward loads improperly or without help. Use proper lifting techniques such as lifting with the legs and keeping a straight back whenever possible. To avoid back injury, get help before trying to lift heavy or awkward loads, stay in good physical condition, and control your weight through diet and exercise.

Workers with limited lifting abilities because of weakness or prior injury should avoid heavy lifting.

These policies help prevent jobsite injuries.

- ✓ Redesign work activities and adapt equipment to minimize awkward movements on the job site.
- ✓ Perform strength-testing of workers, set lifting limits, and provide training for all workers on the causes and prevention of back injuries.
- ✓ Enforce breaks to prevent workers from being in straining positions for long time periods.
- ✓ Share the difficult work among capable crew members.

Awkward loads: Ask for help when moving heavy or awkward loads.

10.6.5 Respiratory Health

Wear a respirator when working in a polluted environment. Common construction dust can contain of toxins including lead, asbestos, and chemicals released by drilling, cutting, scraping. Liquid foam, caulking, and solvents exude toxic organic vapors.

Test your respirators to be sure they have a good fit.

- ✓ Check the straps and face piece to be sure they are soft and free of cracks.
- ✓ Strap on the respirator and adjust the straps to be snug but comfortable.
- ✓ Close the exhalation valve with a hand.
- ✓ Exhale gently and check for leaks around the edges.
- ✓ If there are leaks, adjust or repair the respirator.

Workers with beards, facial scars, and thick temple bars on eyeglasses must use full-face respirators to achieve a good seal.

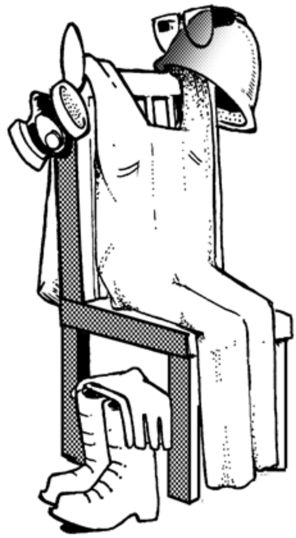
Workers spraying polyurethane foam, for example, should use a respirator canister designed to filter organic vapors, and they should ventilate the area where the foam is being sprayed. For areas like crawl spaces that are difficult to ventilate, workers should use a supplied-air, positive-pressure respirator.

Learn how to recognize asbestos insulation that may be installed around older furnaces and boilers.

Control dust in your client's homes by erecting temporary barriers when you are doing work that may release toxic dust. Wear coveralls when entering attics or crawl spaces. Coveralls should be disposable or laundered professionally.

10.6.6 Hazardous Materials

Your health and safety can be threatened by hazardous materials used on the job. Workers often fail to protect themselves from hazardous materials because they don't recognize and understand their health effects. Breathing hazardous materials, absorbing them through the skin, and coming into eye contact with hazardous materials are common ways workers are affected.



Personal protective equipment: Employees should own and maintain protective equipment to protect themselves from hazardous materials.

OSHA regulations require employers to notify and train employees about hazardous materials used on the job. A Material Safety Data Sheet (MSDS) for every workplace hazardous material should be readily available to employees. Copies of MSDSs are obtained from manufacturers or their distributors. Employees should know where MSDSs are kept and how to interpret them.

Learn how to avoid exposure to hazardous materials used on the job and how to clean up chemical spills. Employees should be instructed to use the appropriate protective equipment that is recommended by the MSDS.

10.7 Lead-Safe Procedures

In 2010, The Environmental Protection Agency's (EPA) Lead-Safe Renovation, Repair, and Painting (RRP) rule became a legal mandate for weatherization work. Previous to 2010, the DOE regulated weatherization work with a set of procedures known as Lead-Safe Weatherization (LSW).

Lead dust is dangerous because it damages the neurological systems of people who ingest it. Children are often poisoned in pre-1978 homes because of paint disturbance during home improvement and because hand-to-mouth behavior is common.

Lead paint was commonly used in homes built before 1978. Contractors working on these older homes should either assume the presence of lead paint or perform tests to rule out its presence. **Weatherization programs are required to observe both the RRP Rule and LSW practices.**

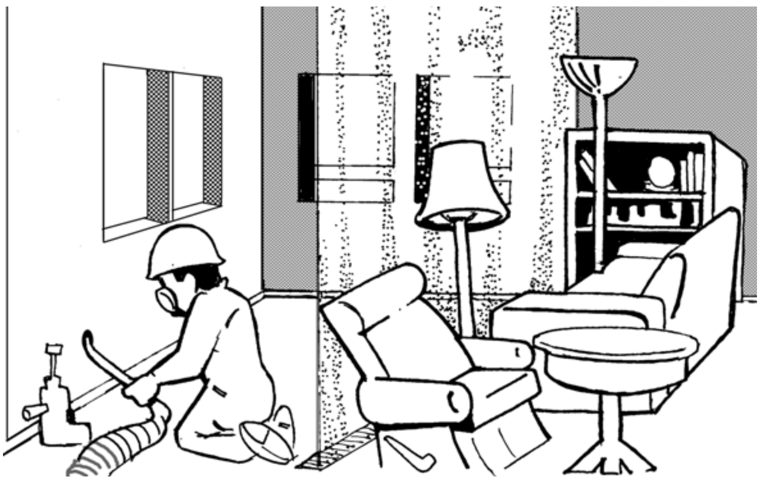
10.7.1 EPA RRP Requirements

The RRP rule requires lead-safe containment procedures whenever workers disturb painted surfaces of more than 6 square feet of interior surface per room or more than 20 square feet of exterior surface per side by cutting, scraping, drilling, or other dust-creating activities in pre-1978 homes. Disturbing paint on windows always requires containment.

The RRP requires certifications, warnings, dust-prevention, dust collection, and housecleaning as summarized here.

- ✓ With pre-1978 homes, either test for lead-based paint or assume that lead-based paint is present.
- ✓ Every pre-1978 weatherization or renovation job must be supervised by a certified renovator with 8 hours or EPA-approved training when workers will disturb more than the minimum paint area or when they will disturb paint on windows.

- ✓ Renovation firms must be registered with the EPA and employ one or more certified renovators.
- ✓ Signs and barriers must warn occupants and passersby not to enter the work area.
- ✓ Floor-to-ceiling dust-tight barriers must prevent the spread of dust from the work area.



Protective sheeting: Dust-tight floor-to-ceiling barriers must separate work areas from living areas, according to EPA's RRP rule.

- ✓ Plastic sheeting must protect surfaces and fixtures within the work area.
- ✓ Workers must clean work surfaces sufficiently to pass an EPA-approved dust-wipe test, conducted by the certified renovator.
- ✓ Workers must not track dust from the work area into the home.

10.7.2 Lead-Safe Work Practices

Lead-Safe Weatherization (LSW) is a set of procedures developed prior to the enactment of the RRP rule. LSW requires the same basic procedures as RRP in pre-1978 homes. When engaging in the paint-disturbing weatherization activities, follow these lead-safe work practices that were established by weatherization experts.

- ✓ Wear a tight-fitting respirator to protect yourself from breathing dust or other pollutants.
- ✓ Confine your work area within the home to the smallest possible floor area. Seal this area off carefully with floor-to-ceiling barriers made of disposable plastic sheeting, sealed at floor and ceiling with tape.
- ✓ Don't use heat guns or power sanders in LSW work.
- ✓ Spray water on the painted surfaces to keep dust out of the air during drilling, cutting, or scraping painted surfaces.
- ✓ Erect an effective dust-containment system outdoors to prevent dust contamination to the soil around the home.
- ✓ Use a dust-containment system with a HEPA vacuum when drilling holes indoors.

Drill shroud connected to HEPA vacuum: Collect dust where you're generating it.

- ✓ Avoid taking lead dust home on clothing, shoes, or tools. Wear boot covers while in the work area, and remove them to avoid tracking dirt from the work area to other parts of the house. Wear disposable coveralls, or vacuum cloth coveralls with a HEPA vacuum before leaving the work area.

Wash thoroughly before eating, drinking, or quitting for the day.

10.7.3 Falls

Falls off ladders and stairs cause 13% of workplace injuries according to the National Safety Council. Falls from the same elevation such as slips and trips account for approximately 7% of workplace injuries.

Broken ladders, and ladders that slip because they haven't been anchored properly, are both major causes of on-the-job falls. Step ladders, for instance, are often used for work that is too far off the ground, forcing workers to stand on the top step or to reach too far.

Ladders: Ladders are the most dangerous tools workers use.

OSHA regulations include these important guidelines for ladder use.

- ✓ All ladders should be kept in good repair, and should be replaced if they have missing steps or cracked side-rails.
- ✓ Broken ladders should be removed from the equipment storage area.
- ✓ Extension ladders should be set to extend at least three feet above the area they access.
- ✓ Ladders shouldn't have a pitch steeper than four feet of rise for each foot the base is away from the building.
- ✓ Ladders must be blocked or tied firmly in place at the top and bottom if the above rule cannot be observed.
- ✓ Metal ladders should not be used where they may come in contact with electrical conductors.

- ✓ Ladders must be maintained free of oil, grease, and other slipping hazards.
- ✓ Ladders must not be loaded beyond the maximum load for which they were built.
- ✓ Workers should avoid carrying heavy loads up ladders and operating power tools from ladders.

Scaffolding must be used when working above-ground for sustained time periods. Scaffolds should be built plumb and level. Each leg should be stabilized so that it supports equal weight as other legs. This is especially important on unlevel ground. Planks should be secured to the structure and handrails provided on the sides and ends of the walkway.

Good housekeeping: Clear stairs and walkways are essential to protect workers and clients alike from falls.

Workplaces should be policed regularly to remove slipping and tripping hazards. Workers carrying loads should establish a debris-free walkway.

10.7.4 Tool Safety

The tools used in construction work are dangerous if used improperly. About 90,000 people hurt themselves with hand tools each year. One moment of inattention can cause an injury that can change a worker's life.

These basic safety rules can reduce the hazards of using hand and power tools.

Electrical safety: Cords should be maintained in good condition. Ground-fault-interrupter cords or outlets should be used in wet conditions.

- ✓ Use the right tool for the job.
- ✓ Keep all tools in good condition with regular maintenance.
- ✓ Inspect tools for damage before using them.
- ✓ Operate tools according to the manufacturer's instructions.
- ✓ Use appropriate personal protective equipment.
- ✓ Use ground-fault-interrupter outlets or extension cords.

10.7.5 Repetitive Stress Injuries

Repetitive stress injuries are caused by over-working certain parts of your body. Poor body posture, such as reaching above your head when operating a power drill, can encourage these injuries. Good work habits help prevent this type of injury.

- ✓ Use a comfortable arm and hand posture when operating tools for a long period of time.
- ✓ Change the angle and location of your work surface frequently.

- ✓ Mix your difficult tasks with easier ones.
- ✓ Carry smaller loads.
- ✓ Take short rest breaks periodically, and stretch any tight muscles during this time.

When you purchase hand and power tools, look for models with ergonomic designs that place less stress on your body.

APPENDICES

A–1 RESOURCES

ASHRAE 2005 Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc; Atlanta GA 1993, www.ashrae.org

ASHRAE Standard 62.2 2010, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc; Atlanta GA 2010, www.ashrae.org

Homeowner's Handbook to Energy Efficiency, Saturn Resource Management, by John Krigger and Chris Dorsi, www.srmi.biz

HVAC Duct Standard, Building Performance Institute (BPI), draft, www.bpi.org

HVAC Quality Installation Specification, ACCA/ANSI 5 QI-2007, Air Conditioning Contractors of America, www.acca.org

International Energy Conservation Code 2009, International Code Council, www.iccsafe.org

International Residential Code 2009, International Code Council, www.iccsafe.org

Residential Energy: Cost Savings and Comfort for Existing Buildings, Saturn Resource Management, by John Krigger and Chris Dorsi, Fourth Edition, 2004, www.srmi.biz

Residential Weatherization Specification Manual, Northwest Regional Technical Forum, 2011, www.nwcouncil.org/energy/rtf/

Standardized Work Specifications for Residential Energy Efficiency Retrofits, DOE EERE Weatherization and Intergovernmental Program, http://www1.eere.energy.gov/wip/wap.html

A–2 Required Diagnostic Equipment

Minimum Equipment For Instrumented Air Sealing

- ✓ Fully instrumented and calibrated blower door, Minneapolis Model 3 or equivalent, capable of measuring CFM_{50} (Cubic feet per minute at 50 Pascals).
- ✓ DG-3 or DG-700 handheld Digital Manometer, or equivalent.
- ✓ Smoke generating equipment.

Minimum Equipment for Heating System Analysis

- ✓ Combustion analyzer.
- ✓ CO testing capacity.
- ✓ Draft gauge or manometer.
- ✓ Heat exchanger leakage testing equipment.
- ✓ Ammeter (sensitive enough to adjust thermostat anticipators).
- ✓ Combustible-gas leak detector.

A–3 R-VALUES FOR COMMON MATERIALS

Material	R-value
Fiberglass or rock wool batts and blown 1″	2.8–4.0
Blown cellulose 1″	3.0–4.0
Vermiculite loose fill 1″	2.7
Perlite 1″	2.4
White expanded polystyrene foam (beadboard) 1″	3.9–4.3
Polyurethane/polyisocyanurate foam 1″	6.2–7.0
Extruded polystyrene 1″	5.0
Sprayed 2-part polyurethane foam 1″	5.8–6.6
Icynene foam 1″	3.6
Oriented strand board (OSB) or plywood $^1/_2$″	1.6
Concrete or stucco 1″	0.1
Wood 1″	1.0
Carpet/pad $^1/_2$″	2.0
Wood siding $^3/_8$–$^3/_4$″	0.6–1.0
Concrete block 8″	1.1
Asphalt shingles	0.44
Fired clay bricks 1″	0.1–0.4
Gypsum or plasterboard $^1/_2$″	0.4
Single pane glass $^1/_8$″	0.9
Low-e insulated dbl. pane unit glass (Varies according to Solar Heat Gain Coefficient (SHGC) rating.)	3.3–4.2
Triple glazed glass with 2 low-e coatings	8.3

A–4 Calculating Attic Insulation

Auditors and inspectors also help crews determine how much insulation is needed for ceilings and walls.

Calculating Attic Loose-Fill Insulation

Loose-fill attic insulation should be installed to a uniform depth to attain proper coverage (bags per square foot) so it attains the desired R-value at the settled thickness. Follow the manufacturer's labeling in order to achieve the correct density to meet the required R-value. Attic insulation always settles: cellulose settles between 10% to 20% and fiberglass settles between 3% to 10%. For this reason, it's best to calculate insulation density in square feet per bag rather than installed thickness.

Insulation Calculation Table

R-Value at 75° F mean Temperature	Minimum Thickness	Maximum Net Coverage	
Desired R-Value of Insulation	Minimum Insulation Depth	Maximum Coverage per Bag (sq. ft.)	Bags per 1000 sq. ft.
R-60	16.0	11.7	85.8
R-50	13.3	14.0	71.5
R-44	11.7	15.9	62.9
R-40	10.7	17.5	57.2
R-38	10.1	18.4	54.4
R-32	8.5	21.6	45.8
R-30	8.0	23.3	42.9
R-24	6.4	29.1	34.3
R-22	5.9	31.8	31.5
R-19	5.1	36.8	27.2
R-13	3.5	53.8	18.6
R-11	2.9	63.6	15.7

Insulation Coverage Table: This table is provided by Weather Blanket Corporation. Coverage and other insulation characteristics will vary from manufacturer to manufacturer.

Example: Calculating Number of Bags

30 FT X 50 FT= 1500 SQ FT

Width | Length | Area of Attic

Step 1: Calculate area of attic
Multiple length times width of the attic to get the area of attic.

R-50 – R-26 = R-24

Desired R | Existing R | R Needed to Add

Step 2: Calculate R-value that you need to add
Subtract existing R from desired R to get the R-value you need to add.

1500 SQ FT ÷ 29.1 = 52 BAGS

Net wall Area | Sq. Ft. Coverage per Bag (from chart) | Estimated Bag Count

STEP 3: Calculate bag count
Divide area of attic by coverage per bag from the chart on the bag (number highlighted in chart on *"Insulation Calculation Table" on page 323*) to get your Estimated Bag Count.

Example: Calculating Density of Attic Insulation

$$\underbrace{1500}_{\text{Area}}\ \text{SQ FT} \times \underbrace{6.4}_{\text{Depth in Inches}}/\underbrace{12}_{\text{Inches per Foot}}\ \text{FT} = \underbrace{800}_{\text{Volume of Insulation}}\ \text{CU FT}$$

Step 1: Calculate volume of installed insulation
Multiple area times depth of the attic insulation to get the volume of insulation.

$$\underbrace{52}_{\text{Number of Bags}}\ \text{BAGS} \times \underbrace{24}_{\text{Weight of a Bag}}\ \text{LBS/BAG} = \underbrace{1248}_{\text{Installed Weight}}\ \text{LBS}$$

Step 2: Calculate the weight of insulation you installed
Take the number of bags times the weight per bag to get the total weight.

$$\underbrace{1248}_{\text{Pounds of Insulation}}\ \text{LBS} \div \underbrace{800}_{\text{Insulation Volume}}\ \text{CU FT} = \underbrace{1.56}_{\text{Installed Density}}\ \text{LBS/CU FT}$$

STEP 3: Calculate density of installed insulation
Divide pounds of insulation by cubic feet of insulation volume to get density.

Note
Density should be between 1.3 and 2.0 pounds per cubic foot or conform to manufacturer's specifications for density, coverage, and bag count for the desired R-value.

A–5 Calculating Wall Insulation

Wall insulation should be installed to a density of 3.5 to 4.5 pounds per cubic foot. These calculations serve to calculate the number of bags necessary to insulate walls and to judge density after completing the wall-insulation job. Calculate the bag count based on information from the agency's insulation supplier.

Example: Calculating Number of Bags for Wall Insulation

(2 x 50 ft) + (2 x 30 ft) = 160 ft

Length — Width — Perimeter of House

STEP 1: Calculate perimeter of house
Calculate the perimeter of the house. If the house is a simple rectangle or near a simple rectangle, use the formula above. If the house has numerous unequal sides, simply add the lengths together to find the perimeter.

160 ft x 8 ft= 1280 sq ft

Perimeter of House — Height of Wall — Total Wall Area

STEP 2: Calculate total wall area
After calculating the perimeter of the house, multiply it times the wall height. This will give you the total wall area.

1280 SQ FT - 150 SQ FT = 1130 SQ FT

Total Wall Area

Area of Windows and Doors

Net Wall Area

STEP 3: Calculate net wall area

Calculate the sum of the areas of windows and doors. Subtract them from the total wall area to get net wall area.

$$\frac{\text{1130 SQ FT X 1.2 LBS/SQ FT}}{\text{24 LB PER BAG}} = \text{57 BAGS}$$

Net Wall Area

Weight of a Bag

Pounds per Square Foot

Bags of Insulation Needed

STEP 4: Calculate bag count

To achieve 4.0 lbs. per cubic foot, multiply net wall area by 1.2 pounds per square foot for a 2-by-4 wall (4.0 lbs. per cubic foot ÷ 12 x 3.5 = 1.2). Then divide by the number of pounds per bag to get the bag count.

Example: Calculating Density of Wall Insulation

1280 SQ FT X 3.5/12 FT = 373 CU FT

Net Wall Area

Inches of Wall Depth

Inches per Foot

Wall Volume

STEP 1: Calculate wall volume

Multiply the wall's surface area times the depth on the wall cavity converted to feet.

57 Bags X 24 lbs/bag = 1368 lbs

Bags Installed

Pounds of Insulation

Weight of a Bag

STEP 2: Calculate weight of insulation
Multiply number of bags you installed times the weight of a single bag to get the weight of the installed insulation.

1388 lbs ÷ 373 cu ft= 3.67 lbs/cu ft

Pounds of Insulation

Insulation Volume

Installed Density

STEP 3: Calculate density of installed insulation
Divide pounds of insulation by cubic feet of insulation volume to calculate density.

A–6 Calculating Mobile Home Insulation

Consider a 14´ x 66´ mobile home, totaling 924 square feet.

- ✓ Ceiling: 9″ cavity at the center and 2″ cavity at the edge with a 2″ batt
- ✓ Belly: $5^1/_2$″ cavity at the wings and $16^1/_2$″ cavity at the center with a 2″ batt fastened to floor bottom
- ✓ Walls: $3^1/_2$″ cavity with a $1^1/_2$″ batt at $7^1/_2$´ high

General formulas

CAVITY VOLUME X DESIRED DENSITY = WEIGHT OF INSULATION

WEIGHT OF INSULATION ÷ POUNDS PER BAG = BAGS OF INSULATION

Ceiling Bag Count Estimates

1. Calculate the average ceiling cavity (9″ + 2″ = 11″) (11″ ÷ 2 = $5^1/_2$″ average cavity)
2. ($5^1/_2$″ cavity minus the 2″ batt = $3^1/_2$″ cavity). The existing insulation batt will compress when additional insulation is added, allow 1″ for compression ($3^1/_2$″ + 1″ = $4^1/_2$″ cavity)
3. Convert $4^1/_2$″ to feet (4.5″/12″ = 0.375´)
4. Multiply 0.375´ x 924 sq. ft. = 346.5 cubic feet
5. Multiply cubic feet by desired density: Fiberglass ceiling insulation density must be 1.0 to 1.5 lbs/cubic foot.

   a. 347 x 1.0 = 347 lbs. / 35(lbs/bag) = 9.9 bags

   b. 347 x 1.25 = 434 lbs. / 35(lbs/bag) = 12.4 bags

   c. 347 x 1.5 = 521 lbs. / 35(lbs/bag) = 14.9 bags

Belly Bag Count Estimates

Calculate the average belly cavity (5-$^1/_2$″ + 16-$^1/_2$″ = 22″)

(22″ ÷ 2 = 11″ average cavity) (11″ cavity – 2″ batt = 9” cavity) The existing insulation batt will compress when additional insulation is added, allow 1″ for compression (9″ + 1″ = 10″ cavity)

1. Convert 10″ to feet (10″ / 12″ = 0.83′)
2. Multiply 0.83′ x 924 square feet = 767 cubic feet
3. Multiply cubic feet by desired density.
4. Belly insulation density at 1.0 to 1.5 lbs/cubic foot.

   a. 767 x 1.0 = 767 lbs. / 35(lbs/bag) = 22 bags

   b. 767 x 1.25 = 959 lbs. / 35(lbs/bag) = 27 bags

   c. 767 x 1.5 = 1151 lbs. / 35(lbs/bag) = 33 bags

A–7 Refrigerator Dating Chart

Refrigerators are listed by brand name, followed by the coding system. If several manufacturers used the same system, they are listed together. Some rules of thumb for easy identification are: (1) Refrigerators that are any color of green, brown, yellow, pink, or blue (actually KitchenAid makes a new unit in cobalt blue); have mechanical handles; have doors held shut with magnetic strips; have rounded shoulders; have a chromed handle; or have exposed "house door" type hinges are at least 10 years old, and (2) the following brands have only been manufactured since around 1984 - Roper, Estate, KitchenAid, Caloric, Modern Maid, and Maytag.

Brand(s)	What to look for	What to avoid	How to decode	Example
Montgomery Wards, Signature (2000)	Serial # - 1st two digits	n/a	Reverse the digits	56xxxxx = 1965
Sears, Kenmore, Coldspot	Model # - 1st & 3rd digits after (.)	n/a	Combine the digits	xx.6x2xxx = 1962
Whirlpool	Model # - 1st 3 letters (pre 1982) Serial # - 2nd digit (post 1982)	Serials with letters	No need as 1st two digits Add "198_" to it	ABCxxx = pre 1982 x2xxx = 1982
Amana	Serial # - 1st digit (pre 1986)	n/a	BLACKHORSE B=1, L=2	Hxxxx = 1966 or 1976 61 is the oldest
Frigidaire	Serial # - 1st & 4th digit (pre 1989)	Serials with no letter in the 4th space	Add "196, 197, or 198" to the 1st digit. The letter in the 4th space is a month code used only on older models.	3xxBxx = 1973 or 1983
Gibson, Kelvinator	Serial # - 3rd digit (pre 1989)	n/a	Add "196, 197, or 198" to it	xx3xx = 1963 or 73 or 83
White, Westinghouse	Serial # - 2nd letter (pre 1989)	Serials without letters	A,V,W=78, B=79, C=80 etc. pre-1978, R=74, U=77 etc.	xLxxx = 1988 74 is the oldest year
Tappan, O'Keefe & Merritt	Serial # - 7th digit (pre 1989)	n/a	Add "196, 197, or 198" to it	xx xxx-x8xx = 1968 or 78 or 88
Admiral, Crosley, Norge, Magic Chef, Jenn Air	Serial # - last letter	n/a	A=1950 or 1974 (+14 yrs) B=1951 or 1975, etc.	xxxxxxD = 1953 or 1977
General Electric (GE)	Serial # - 2nd letter	n/a	See chart below	xGxxx = 1950 or 1980
Hotpoint	Same as GE with some exceptions. See GE and Hotpoint exceptions chart below			

GE Decoder Chart:

A = 44, 65, 77, 89	B = 45, 66	C = 46, 67	D = 47, 68, 78, 90	E = 48, 69	F = 49, 79, 91	G = 50, 80, 92
H = 51, 81, 93	J = 52	K = 53	L = 54, 70, 82, 94	M = 55, 71, 83	N = 56, 72	P = 57, 73
R = 58, 84	S = 59, 85	T = 60, 74, 86	V = 61, 75, 87	W = 62	X = 63 Y = 64	Z = 76, 88

Hotpoint Exceptions: U = 61, V = 62, W = 63, X = 64, Y = 65, Z = 66, A = 67, B = 68

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A–8 Measuring BTU Input on Natural Gas Appliances

Use the following procedure when it's necessary to measure the input of a natural gas appliance.

1. Turn off all gas combustion appliances such as water heaters, dryers, cook stoves, and space heaters that are connected to the meter you are timing, except for the appliance you wish to test.
2. Fire the unit being tested, and watch the dials of the gas meter.
3. Carefully count how long it takes for one revolution of $^{1}/_{2}$, 1, or 2 cubic-foot dial. Find that number of seconds in *Table Appendices-3* in the columns marked "Seconds per Revolution." Follow that row across to the right to the correct column for the $^{1}/_{2}$, 1, or 2 cubic-foot dial. Note that you must multiply the number in the table by 1000. Record the input in thousands of BTUS per hour.
4. If the measured input is higher or lower than input on the name plate by more than 10%, adjust gas pressure up or down within a range of 3.2 to 3.9 (inches of water column (IWC) until the approximately correct input is achieved.
5. If the measured input is still out of range after adjusting gas pressure to these limits, replace the existing orifices with larger or smaller orifices sized to give the correct input.

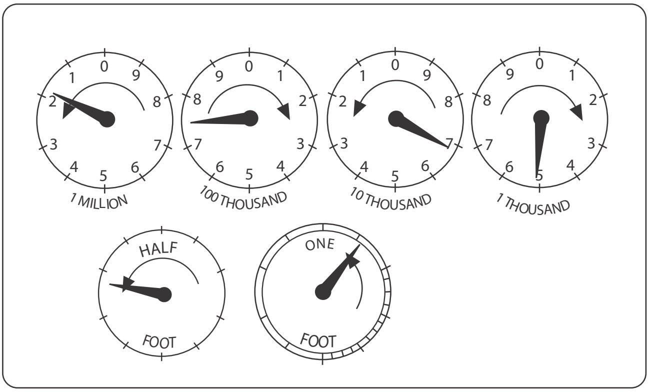
Table Appendices-3:Input in Thousands of Btu/hr for 1000 Btu/cu. ft. Gas

Seconds per Revolution	Size of Meter Dial			Seconds per Revolution	Size of Meter Dial			Seconds per Revolution	Size of Meter Dial		
	1/2 cu. ft.	1 cu. ft.	2 cu. ft.		1/2 cu. ft.	1 cu. ft.	2 cu. ft.		1/2 cu. ft.	1 cu. ft.	2 cu. ft.
15	120	240	480	40	45	90	180	70	26	51	103
16	112	225	450	41	44	88	176	72	25	50	100
17	106	212	424	42	43	86	172	74	24	48	97
18	100	200	400	43	42	84	167	76	24	47	95
19	95	189	379	44	41	82	164	78	23	46	92
20	90	180	360	45	40	80	160	80	22	45	90
21	86	171	343	46	39	78	157	82	22	44	88
22	82	164	327	47	38	77	153	84	21	43	86
23	78	157	313	48	37	75	150	86	21	42	84
24	75	150	300	49	37	73	147	88	20	41	82
25	72	144	288	50	36	72	144	90	20	40	80
26	69	138	277	51	35	71	141	94	19	38	76
27	67	133	267	52	35	69	138	98	18	37	74
28	64	129	257	53	34	68	136	100	18	36	72
29	62	124	248	54	33	67	133	104	17	35	69
30	60	120	240	55	33	65	131	108	17	33	67
31	58	116	232	56	32	64	129	112	16	32	64
32	56	113	225	57	32	63	126	116	15	31	62
33	55	109	218	58	31	62	124	120	15	30	60
34	53	106	212	59	30	61	122	130	14	28	55
35	51	103	206	60	30	60	120	140	13	26	51
36	50	100	200	62	29	58	116	150	12	24	48
37	49	97	195	64	29	56	112	160	11	22	45
38	47	95	189	66	29	54	109	170	11	21	42
39	46	92	185	68	28	53	106	180	10	20	40

Natural Gas Heat Content

Note that *Table Appendices-3 on page Appendices-333* assumes that gas is 1000 BTUs per cubic foot. Where BTU values differ from this figure — especially at high elevations — obtain the correct BTU value from the gas supplier and apply the formula shown below.

(BTU VALUE FROM SUPPLIER ÷ 1000) X BTU/HR INPUT FROM TABLE = ACTUAL BTU/HR INPUT OF APPLIANCE



Clocking the Meter: Count the number of seconds per revolution of the one-foot dial and refer to *Table Appendices-3 on page 333* to find the appliance's input.

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